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ORIGINAL ARTICLES.

I.—Four Theories of the Age and Origin of the Dartmoor Granites.

By A. R. Hunt, M.A.

FOUR Theories of the Age and Origin of the Dartmoor Granites have been lately current, viz.:—

(1) The ordinary Plutonic of Sir H. de la Beche.

(2) The Laccolitic-Plutonic of Mr. W. A. E. Ussher.[1]

(3) The Volcanic of Mr. R. N. Worth.[2]

The above all assume the exclusively post-Carboniferous age of the granite, owing to its intrusion into the adjacent Carboniferous rocks; one of the best attested facts in geology.

(4) The combined pre-Devonian non-intrusive and post-Carboniferous intrusive (both plutonic), advanced by myself in 1889.[3]

Mr. Ussher has recently withdrawn his provisional[4] laccolitic hypothesis, on stratigraphical grounds, in favour of one which is practically equivalent to No. 4.[5]

As it is impossible to compress the work of some four years into a magazine article, the present paper must be confined to a sketch of my main argument.

My friend Mr. Worth has, with characteristic generosity, lent me the diagrammatic woodcut illustrating his ideal volcano; accompanied by the following remark: "Please do not limit your views of me; you owe it to yourself to make your case as strong as possible, and we shall not differ outside our theories." A too generous opponent indeed, and one hard to oppose.

The following woodcut was published to illustrate Mr. Worth's paper, "The Dartmoor Volcano," Trans. Plymouth Inst. 1888–89.

Mr. Worth brought his theory in the plainest language before the Geological Society in 1889, when it was discussed by our leading petrologists, apparently accepted by Prof. Bonney and Mr. Hudleston, and not objected to on principle by anyone.[6]

Primâ facie, however, there seems a serious objection to Mr. Worth's volcanic hypothesis, as it involves the "Elevation-crater theory" pure and simple.[7]

[1] Trans. Devon. Assoc. vol. xx p. 154.
[2] "The Dartmoor Volcano," Trans. Plymouth Institution, etc., 1888–89.
[3] Trans. Devon. Assoc. vol. xxi. p. 238. [4] Trans. Devon. Assoc. vol. xx. p. 156.
[5] Proc. Som. Archæological Soc. vol. xxxviii. p. 204.
[6] Q.J.G.S. vol. xlvi. pp. 80–82.
[7] See Geikie, Text Book of Geology, pp. 241, 242.

[The publication of this article has been unavoidably delayed.—Edit. Geol. Mag.]

I would venture to submit this preliminary point to geologists before making any attempt to discuss the volcanic theory of Dartmoor in detail.

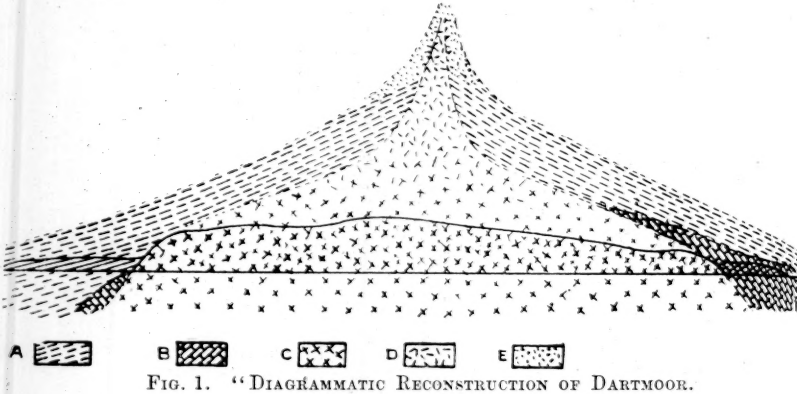


FIG. 1. "DIAGRAMMATIC RECONSTRUCTION OF DARTMOOR.

It must be understood that this sketch is diagrammatic and has no pretensions to scale, and that it is mainly suggestive and purposely made as simple in its conditions as possible. All below the horizontal line, which represents datum, is purely hypothetical; and all above the curved line, which indicates generally the present surface contour of the Moor and bordering rocks from north to south. This superstructure has been removed. A, represents Carboniferous rocks; B, Devonian; C. Granite; D, Felsite; E, Volcanic Material and Ejectmenta. The wedge-like intrusion of the granite has tilted and broken through the upper or Carboniferous rocks, and has thrust as well as heaved the lower or Devonian."

My own pre-Devonian hypothesis was first advanced at the Tavistock meeting of the Devonshire Association: on which occasion the following epitome of my paper, with the valuable comments of the President, Mr. W. H. Hudleston, F.R.S., appeared in the "Western Morning News." As reporters could have made nothing of so technical a subject, I conclude that the President's remarks were personally revised for the Press, as was my own abstract.

"*The Age of the Granites of Dartmoor and the English Channel.*

Mr. A. R. Hunt read a paper on the Relation of the Granites of Dartmoor to the Granites of the English Channel. The author drew attention to the following points of difference between the granites of Dartmoor and those trawled in the English Channel:—The Dartmoor granites were characterized by fracture, by the frequent presence of tourmaline, and were not gneissose. The Channel granites indicated compression, were sometimes hornblendic, and were associated with gneisses. The Dartmoor granites were intersected by injected and infiltrated veins. No veinstones (though such were very durable) had been forthcoming from the Channel. The quartzes in the Dartmoor granites and in both classes of veins contained fluid inclusions of brine, with cubic crystals of salt. No salt had been detected in the Channel granites. Chiastolite occurred on the borders of Dartmoor, kyanite in the Bolt schists bordering the

Channel[1]—chemically identical, they differed only in specific gravity, the heavier mineral indicating the greatest compression. From these facts the author argued that the Channel and Dartmoor granites were both originally of pre-Devonian and probably of Archæan age. That after the deposition of the Devonian and Carboniferous rocks, the Dartmoor area was fissured by the same earth-movements which compressed the Channel area. The sea obtained no access to the Channel granite, but penetrated the Dartmoor area. The crushing of the lower rocks supplied the heat, whilst the sea supplied the water, which under high pressure dissolved the Archæan granite to be reconsolidated with salt here and there caught up in its quartzes. The reconstituted granites traversing the culm slates were truly post-Carboniferous; but the mass of Dartmoor is Archæan, occasionally altered by super-heated brine accompanied by boracic acid.

"The President said it was unquestionable that a very ingenious theory had been propounded by Mr. Hunt, although very different to that which had been hitherto held by most geologists. Without going very closely into the question, or dealing otherwise than superficially with the paper, he thought it was perfectly clear that the Dartmoor granite and the Channel granite were of quite a different age, and had an entirely different origin. To that extent he was in conformity with the views of the author. But the granites were quite different mineralogically. There was one very great difference, namely, that the Channel granites were not metalliferous in the way that the Dartmoor granites were. There were no granites in the British islands which were so metalliferous as the Devon and Cornwall granites, and it appeared to him that they had a very different origin to other granites. For that simple reason, as regarded the age of the Dartmoor granite, it appeared to him that the usual view that it was post-Carboniferous was the one most in accordance with the facts of the case, as far as he had been able to judge. But when they came to the differences of the mineral composition of these granites, he thought they had further proof that the alteration of Dartmoor granite had been produced subsequently by the numerous fissures formed. These fissures had been more or less injected by corroding aqueous vapours containing large quantities of chlorides and fluorides of heavy metals. These crystals of salt, which Mr. Hunt had found in such considerable quantity, he thought (it) excessively probable had been formed from hydrochloric acid gas acting on the soda in the rocks. That appeared a very much more reasonable explanation of the origin than that they came from the sea, or had anything to do with the sea whatever."

The question as to the marine or plutonic origin of the brine-inclusions referred to is of transcendent importance in connection with the question as to whether the water ejected by volcanoes is of meteoric or marine origin, or derived from the interior magma.

Hypotheses that might meet the case of pure water might well fail to explain the presence of the chlorides of sodium and potassium.

Having carefully examined the rocks in the light of Mr. Hudleston's

[1] Note. Withdrawn, Geol. Mag. 1892, p. 291.

suggestion, I submitted the question to the British Association at Leeds. The following extract is from the published abstract of my paper:—

"The theory of the marine origin of the saline inclusions in the Dartmoor rocks seems to harmonize well with the view commonly entertained that the chlorine and chloride of sodium emitted by volcanoes are derived from the sea.[1]

"In the case of volcanoes the presence of hydrogen and chlorine may be accounted for by the dissociation of the water and of the chloride of sodium by the intense heat, and the combination of the two gases thus formed would result in the production of hydrochloric acid.

"In the case of the cooler granites there is no question of dissociation and of gases, but of the entanglement of brine and steam at more moderate temperatures.

"Thus the access of salt water to highly heated rocks seems to account for some of the more important gases emitted by lavas and of the more characteristic fluid inclusions caught up by granites.

"An alternative theory, that the crystals of salt in the Dartmoor rocks 'had been formed from hydrochloric acid gas acting on the soda in the rocks,' does not seem to the author to account for the crystals in the quartz-veins of the culm slates, or to explain the complete permeation of the granite by the chloride of sodium. Moreover, the one theory accounts for the presence and origin of the hydrochloric acid as well as of the soda, whereas the other has to assume the previous existence of soda and the advent of hydrochloric acid from unknown quarters."[2]

The very title of this paper was omitted from the newspaper reports, it being dismissed as being merely of local interest!

Mr. Ussher's last paper referring to Dartmoor appeared in 1892, and General Mc'Mahon's in 1893. In the discussion which ensued on the reading of the latter, Professor Bonney is reported to have said that "In his opinion Mr. Ussher's theory was quite untenable. If the fusion of a peripheral portion of the Dartmoor mass was due to crushing . . . . Was there any evidence that a rock could be fused by pressure alone, any more than by a gentle stewing in sea-water which also had been suggested? . . . No good was done for science by proposing hypotheses which, in avoiding one difficulty, raised a number of others far more formidable."[3] On the same occasion General Mc'Mahon said that "the word used by Mr. Ussher was 'fusion,' and it was applied to the results of the N. and S. squeeze on the rigid and obstructing pre-Devonian rocks."[4]

There seems great misapprehension here. So far from Mr. Ussher attributing fusion of the Dartmoor granite to "pressure" or "crushing," or to a "N. and S. squeeze," he seems never even to have used the terms "pressure" or "crushing" in reference to the granite, and his only suggestion of a possible source of heat appears to be "a rise of the isogeotherms or plutonic action" (a quotation from

[1] See Characteristics of Volcanoes, J. D. Dana, p. 8.
[2] Report Brit. Assoc. 1890, p. 815. [3] Q.J.G.S. vol. xlix. p. 397. [4] *Loc. cit.* p. 397.

my own paper). He also states that "the metamorphism (in the granites) was produced *after*, and perhaps as a new phase in, the great dynamic movements to which the contortion and cleavage of the Palæozoic rocks are due."[1] And in another place we learn that the fusion of the obstructive masses took place *after* the mechanical effects produced by their obstruction had attained their maxima.[2]

So far as I can gather from a careful study of Mr. Ussher's and General McMahon's papers, Mr. Ussher's almost incidental references to the behaviour of the granite itself (for his main point is the sedimentary rocks) have been misapprehended.

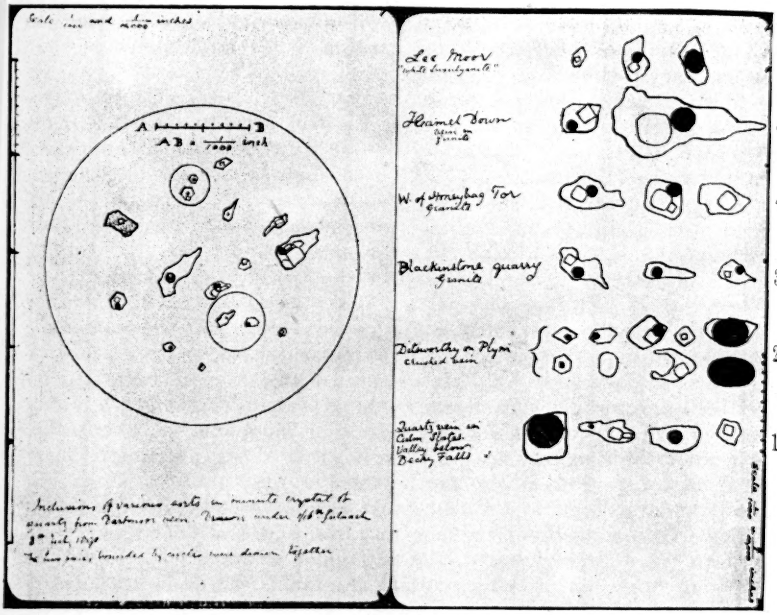
It would almost appear, however, that Prof. Bonney's questions, whilst missing their mark in Mr. Ussher, force me to take the defensive, owing to my having written—"The crushing of the lower rocks supplied the heat."[3] This hypothesis, whether tenable or not, is fairly orthodox, for, assuming that "pressure" is used here for friction or crushing (the results of pressure), we may turn to Mallet for experiment, and to Callaway for observation. Mr. R. Mallet, F.R.S., has the following passage in the Quarterly Journal of the Geological Society:—"The writer has thus shown that crushing alone of rocky masses beneath our earth's crust may be sufficient to produce fusion."[4] Describing a particular rock, Dr. Callaway writes in the same publication:—"During the metamorphism partial fusion, resulting in plasticity, took place. This effect is found so often to occur where the shearing is at its maximum, while the adjacent rock is merely a crushed solid, that the generation of heat by the shearing-process becomes a probable inference."[5]

It may be as well to point out that I never suggested a crushing of any portion of the Dartmoor granites that has ever been seen by man. As already stated, the Dartmoor granites as exposed to view are "characterized by fracture,"[6] and instead of indications of pressure there is every sign of relief of pressure. Felspars and quartzes are occasionally split by divisional planes and re-cemented; but I know of no instance even of dislocation, much less of crushing or shearing, in the main mass of the granite. However, there is nothing to prevent the upper crust having been in a state of strain, while lower horizons were under stress, so, in these latter, dynamic action may well have supplemented the earth's heat in producing the comparative moderate temperatures indicated by the granite. With respect to the "fusion . . . . by a gentle stewing in sea-water" referred to by Professor Bonney, it is possible my critic may have misunderstood the following sentence, viz. "altered . . . . by *moderate* heat in the presence of salt water."[7] By moderate heat I merely meant a temperature not much, if at all, exceeding the critical temperature of water, and the term was used relatively to volcanic temperatures, which latter seem inadmissible if only because they would dissociate the elements in the chloride inclusions.

[1] Proc. Somerset Archæological Soc. vol. xxxviii. p. 217.
[2] *Loc. cit.* p. 208. [3] See *ante*, p. 99. [4] Q.J.G.S. vol. xxxi, p. 517.
[5] Q.J.G.S. vol. xlix, p. 422. [6] See *ante*, p. 98.
[7] Report Brit. Assoc. 1889, p. 570.

The particular point I desire to emphasize on the present occasion is the intimate association in the Dartmoor area of fluid inclusions, containing cubic and other crystals, with fluid inclusions consisting apparently of plain water.

FIG. II. FIG. III.



In a slice of a veinstone from near Manaton there is an hexagonal crystal of quartz about $\frac{1}{30}$ inch in diameter. The gradual growth of this crystal is defined by tourmaline and tourmaline microliths.[1] It is crowded with inclusions, both irregular and with crystalline outlines (*i.e.* negative crystals). We can see that it has never been viscid, plastic, or colloid, or anything else than a mineral gradually crystallized out from solution.

Within this crystal, and not more than $\frac{1}{2000}$ inch apart, there are two inclusions, both of them negative hexagons, with small bubbles; but one contains a cube, and the other contains none. There is also a negative hexagon with a relatively large bubble, $\frac{1}{5000}$ inch distant from an irregular inclusion with a very minute bubble.

Among the liquid inclusions, as figured above (Fig. II.), there is a tourmaline microlith which seems to have caught up a cube of some chloride during crystallization. The inclusions drawn are selected, and not in their relative positions, excepting the two couples within small circles.

[1] See Trans. Devon. Assoc. vol. xxi. p. 261, plate, fig. 3.

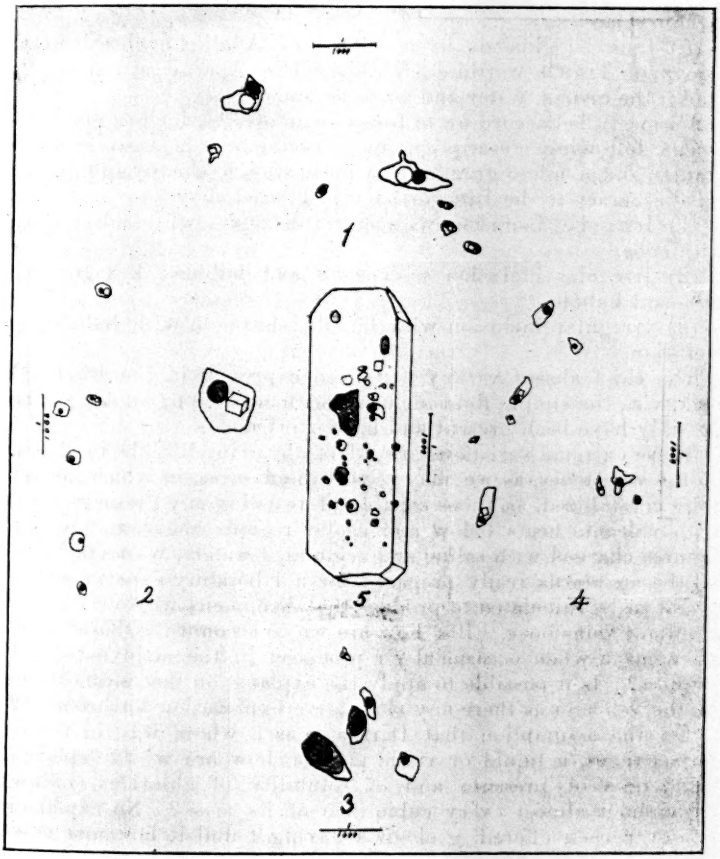
On the second cut (Fig. III.) are drawings selected from six specimens, of which the five lower ones deserve special notice, viz., commencing with the lowest:—

(1) Quartz vein in Culm slates, valley below Becky Falls.

(2) "Ditsworthy—vein is intrusive in a tongue of slate which extends into the granite across the Plym valley from Ringmoor—a very narrow strip." (Worth.)

Quartz, decomposed felspar, white mica, brown tourmaline decomposing into green. A very remarkable rock, with inclusions (as shown above) varying to the utmost extreme.

Fig. IV.



(3) Blackinstone Quarry, and (4) Honeybag Tor, ordinary granites.

(5) Hamel Down, quartz-felspar-tourmaline vein; negative crystal apparently based on the rhomboidal prism.

It will be observed that the same type of liquid inclusions, in similar variety, can be traced from the simple quartz vein, through various injected or infiltrated compound veins, to the ordinary granite of Dartmoor.

Description of Fig. IV.:—

(1) Liquid inclusions in a quartz-vein in Culm slate in the valley below Houndtor Wood, south of the Becka brook.

(2) Liquid inclusions in the quartz of Trowlesworthite.

(3) Inclusions with one and two liquids in a granite (No. 20) trawled in English Channel (for comparison).

(4) Liquid inclusions from normal porphyritic Dartmoor granite, Heytor Quarries.

(5) Liquid inclusions in a crystal of Apatite enclosed in the quartz of Trowlesworthite (No. 2). The Apatite contains plain fluid; the quartz, water and cubic crystals.

All magnified according to linear scale of $\frac{1}{1000}$ inch as given.

The following description of a contact slide between coarse granite and a micro-granite vein in Lustleigh Cleave applies with equal accuracy to the Ditsworthy vein figured above:—

(1) Irregular inclusion with cube; hexagon with cube; rhomb with cube.

(2) Irregular inclusion with cube and bubble; hexagon with cube and bubble.

(3) Irregular inclusion with bubble; hexagon with bubble; gas inclusion.

The chief absent variety here is one present in the Ditsworthy rock, viz., the simple fluid inclusion without cube or bubble; it may possibly have been present and been overlooked.

These extreme variations are all of them intelligible in the case of the veinstones, as we may regard the fissures, in which the latter were crystallized, as tubes capable of resisting any pressure. Then with volcanic heats below and cooler regions above, and with the fissures charged with saline and acidulated waters, we seem to have all the apparatus ready prepared for a laboratory experiment on a grand scale, calculated to produce the phenomena we now see in the resultant veinstones. But how are we to account for these identical phenomena when occasionally reproduced in the main mass of the granite? Is it possible to apply the explanation that meets the case of the veins, or is there any alternative explanation forthcoming?

On the assumption that Dartmoor as a whole was, in Carboniferous times, a liquid or viscid magma, how are we to explain the differences of pressure and of solubility of chlorides, indicated throughout almost every cubic inch of its mass? No explanation has ever been offered, geologists having found it far more easy to minimise the importance of the facts than to account for them.

It is usually admitted that the tourmaline of Dartmoor is commonly a secondary mineral; or, as its presence implies the introduction of two new elements into the granite (fluorine and boron), it is perhaps more accurately described as an imported mineral. Assuming the

existence of an ancient granite, a sufficient explanation suggests itself, both of the presence of the imported tourmaline and of the imported chlorides. If a piece of granite be heated in an ordinary fire, even to a bright red heat, and cooled, its general appearance is not much affected; it is still rigid enough to be sliced for the microscope, but differential expansions in its dissimilar minerals have rendered it permeable by fluids, as can be readily tested by a dye, such as aniline. Now, if a deep-seated granite were exposed to alterations in temperature sufficient to set up such differential expansions, the most compact rock would be minutely cracked throughout, and be rendered permeable by liquids and gases, especially under pressure. The doctrine of the rise and fall of the earth's internal heat through the crust, by the deposition and denudation of sediments, has long been accepted by geologists. All we require is an application of this doctrine to Dartmoor, so that our granite, before or during Carboniferous times, should have suffered sufficient alterations of temperature to render it porous, and so lay it open to the invasion of solvent liquids or gases. Indeed, many granites are so rotten and decomposed, from whatever cause, that they suck up fluids like a sponge.

Now a porous granite being granted, there is little further difficulty; for although some modern geologists decline to entertain the hypothesis that sea-water could gain access to heated granite and set up chemical changes therein, the weight of the evidence is against them. Years before a section was cut, or the chlorides in liquid inclusions discovered by Dr. Sorby, the almost omniscient De la Beche, with well nigh incredible foresight, pointed out the probability of saturated solutions of salt being accumulated in granite, by sea-water obtaining access to the rock when highly heated.[1] De la Beche also pointed out the important chemical effects which the various salts dissolved in sea-water might be expected to have on the granite itself.[2]

Given a porous granite, covered by sedimentary rocks thick enough to bring the internal heats within reach of a superincumbent ocean, and we have all the machinery requisite for the solution of quartz[3] and silicates; and, with the addition of fluorine and boron, for their redeposition in a variety of forms such as quartz, tourmaline, topaz, fluor spar, and triclinic felspars; all of which occur as introduced minerals in the west country granites.

The late Mr. J. A. Phillips has recorded the occurrence of saline water in Huel Clifford mine, 1320 feet below the sea-level.[4] Prof. Le Conte has calculated that at a depth of 10,000 feet below the surface the temperature would be 230 F.,[5] a very moderate depth in terms of ocean soundings, being 1666 fathoms. But even 230 F. is a temperature not to be neglected, seeing that the glass tubes of the water guages of ordinary locomotives become corroded.

[1] Report on the Geology of Cornwall, Devon, etc., p. 378. [2] *Loc. cit.* p. 387.
[3] Mr. J. B. Hannay has kindly informed me that he has dissolved quartz in superheated steam and produced transparent quartz crystals thereby.
[4] Phil. Mag. 1873 (2), p. 32. [5] *Loc. cit.* p. 45.

However, in the case of Dartmoor, there is no necessity to limi the temperature to that of the isogeotherm of the granite itself i post-Carboniferous times; as, on our hypothesis of the rock being permeable by liquids, the heated gases and liquids may have been derived from much lower levels.

But to return to the evidence of the associated saline and fresh water inclusions: these seem to indicate a consolidated granite subsequently heated, cracked, and permeated by liquids. The question at once arises whether this granite, the original granite of Dartmoor, first consolidated before or after the deposition of the adjacent Devonian and Carboniferous rocks? If after their deposition, it is inexplicable how a mass of heated, deep-seated granite supposed by many to be even volcanic in character, twenty miles in diameter, and which as such must have taken centuries to cool could have had so little effect on the adjacent sedimentaries as to fail in every known instance to obliterate the exact point of contact. If before their deposition, then the granite is pre-Devonian, which is the point of my argument.

It seems likely enough that a partial aqueo-igneous solution of the ancient Dartmoor granite, accompanied by earth movements in post-Carboniferous times, would have resulted in the injection of the dissolved material into fissures of all kinds, and especially into the main lines of weakness between the granite and the adjacent sedimentaries. Thus all the local contact-alterations, so insufficient if attributed to the action of the main mass of the granite on its primary consolidation, would find an adequate cause in the contact of the newer intrusive or re-constituted granites, which, so far as I am aware, never occur in any considerable mass relatively to the whole crystalline area.

It would greatly facilitate further research in the Dartmoor area, if the following three points could be definitely decided:—

(1) Whether the volcanic hypothesis is tenable?

(2) Whether the chlorides in the quartzes are of marine or plutonic derivation?

(3) An explanation of the immediate juxtaposition of brine and fresh-water inclusions.

It is to be regretted that the problems connected with fluid inclusions excite at the present time so little interest, even when not treated with absolute contempt. Some of them are perplexing enough. Take for example Trowlesworthite.[1] In my slide of this rock a certain crystal of Apatite (identified by Mr. Harker) contains liquid inclusions with small and active bubbles and with no indication of chlorides; whereas the quartz contains some inclusions with salts and others apparently without. This rock thus presents even greater complications than the granite mentioned by Dr. Sorby in which the felspars contained fresh water and the quartzes brine.[2]

At the time that Dr. Sorby delivered his Presidential Address to Section C. at Swansea, it was generally supposed that while super-

[1] See Worth, Trans. Dev. Assoc. vol. xix, p. 494.

[2] Rep. Brit. Assoc. 1880, p. 570.

heated water dissolved solids, superheated steam above the critical temperature did not do so. The brine and freshwater inclusions were therefore explicable on the hypothesis that the felspars caught up compressed non-solvent steam above the critical temperature, and that the quartzes caught up solvent water under that temperature. Of late years, however, experimentalists seem agreed that compressed gas above the critical temperature has even greater solvent properties than the superheated liquid under that temperature. Thus the hypothesis that the purity of the water in different minerals may be owing to the inclusion of highly compressed non-solvent steam above the critical point seems to break down. It seems possible that certain experiments made by Mr. J. B. Hannay may clear up this particular difficulty. According to Mr. Hannay,

(1) "Gas must have a certain density before it will act as a solvent, and when its volume is increased more than twice its liquid volume its solvent action is almost destroyed" (Proc. Roy. Soc. vol. xxx. p. 486).

(2) "Retaining the volume the same, the higher the temperature the greater the solvent power" (Proc. Roy. Soc. vol. xxx. p 486).

(3) "The vaporous state can be clearly defined as a distinct state of matter."

"A vapour over a liquid holding a coloured solid in solution is colourless, but on passing the critical temperature the whole becomes coloured" (Proc. Roy. Soc. vol. xxxiii. p. 321).

Thus, according to Mr. Hannay, superheated water under the critical point is a solvent liquid. Superheated steam under the critical point is a non-solvent vapour. Superheated steam over the critical point is a gas, and, if compressed to two volumes of the liquid and less, is a solvent.

In the case of the felspar and apatite above referred to, if these minerals crystallized below the critical temperature, but under pressure not sufficient to compress the vapour into liquid, they would enclose compressed non-solvent vapour, which would ultimately condense into fresh water. Another explanation of these minerals enclosing plain water, even above the critical point, would be the absence of chlorides, or of soluble minerals alien to the growing crystals, during the process of crystallization.

Liquid inclusions of the normal type in granitoid rocks contain plain water with mobile, and sometimes very active, bubbles. Inclusion of salts are exceptional. The presence of fresh water during crystallization of the quartz would account for the one sort; and the presence of sea water would account for the other. The difficulty lies in the rapid alterations from fresh water to salt, and *vice versâ*.

The analogy of the marine boiler and engine, with condensation of fresh water in the condenser, and possibly in the cylinders, and with accumulation of brine in the boiler, suggests a possible explanation of these complicated inclusions, viz. heat acting on salt water under pressure producing rapid alternations of brine, steam, and fresh water, during the crystallization of the minerals concerned. It may be noticed that the variations are often so great, and the

alternations apparently so rapid, within very minute areas, say $\frac{1}{10000}$ of an inch, that the hypothesis of any general fluidity or viscosity of the rock-masses in which such inclusions occur is very difficult to reconcile with the phenomena observed.

As exception has been taken in the columns of the GEOLOGICAL MAGAZINE to my attempting problems beyond my powers, I may mention that I have repeatedly thrown this Dartmoor question aside as too overwhelmingly difficult; on the other hand it has seemed a pity that observations which may be of use to other workers should be entirely lost.

It may also be borne in mind that the last words written hitherto by Dr. Sorby on the subject of inclusions and crystalline rocks, are the significant ones, as true now as when they were addressed to the Geological Section of the British Association in 1880—"There is still much to be learned respecting the exact conditions under which some of our commonest rocks were formed."

POSTSCRIPT.—Fig. 4 represents five distinct groups of inclusions, drawn separately with the camera lucida, the inclusions of each group being in their relative positions. The five drawings for the purpose of the process block were marshalled on a sheet of white paper and reduced by photography.

II.—WOODWARDIAN MUSEUM NOTES.

CERTAIN FOSSILS FROM THE LOWER PALÆOZOIC ROCKS OF YORKSHIRE.

By SIDNEY H. REYNOLDS, M.A., F.G.S.

(PLATE IV.)

I UNDERTOOK this description of certain fossils from the Lower Palæozoic rocks of Yorkshire at the request of Mr. Marr. The late Mr. Thomas Roberts had begun the piece of work, but left it unfinished. Nearly all the fossils referred to were collected by a party of Cambridge geologists, under the guidance of Prof. Hughes, in the Summer of 1889. The fossils come from two horizons, viz.:—

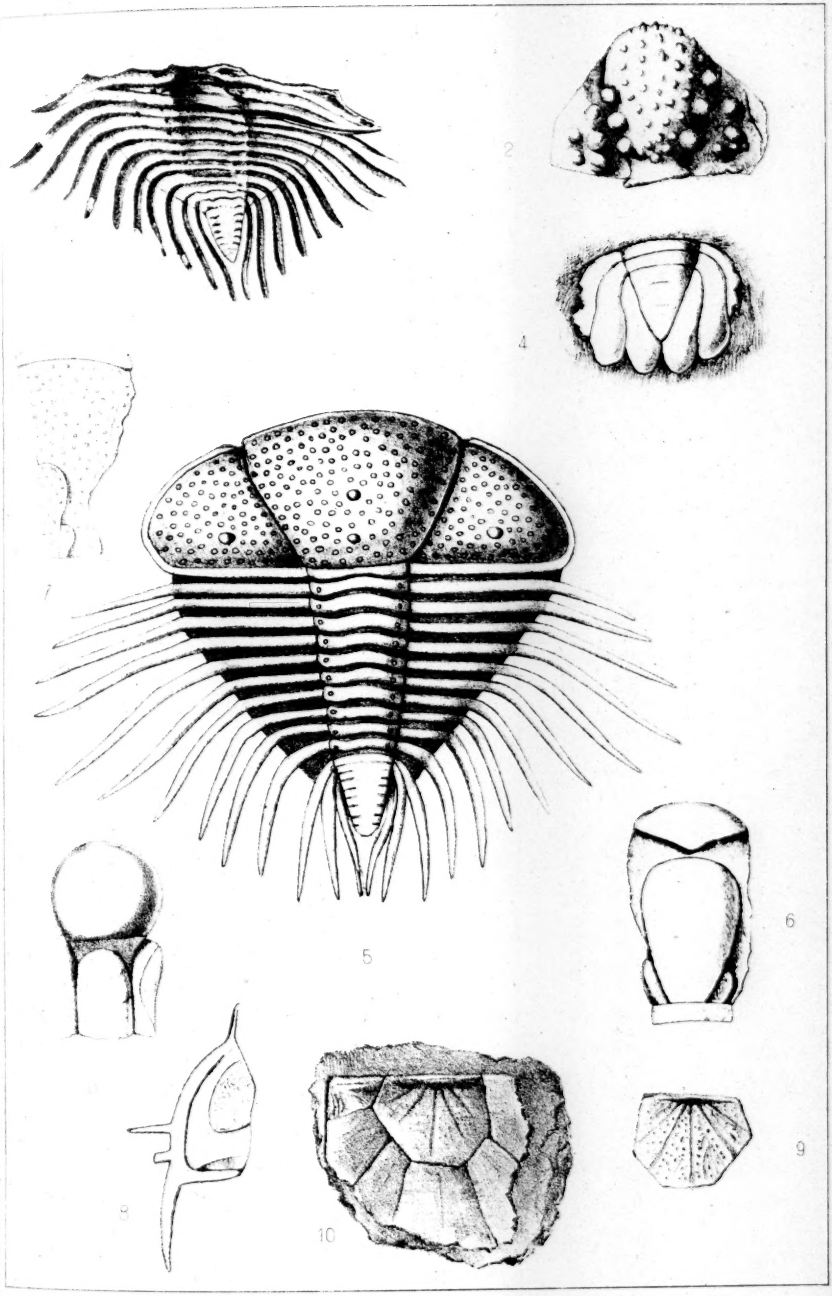
1. The *Phacops elegans* zone=Stockdale Shale series (Valentian) of Wharfe.
2. The Bala beds=Coniston Limestone series of Norber Brow and Wharfe.

Mr. Marr (GEOL. MAG., Dec. III. Vol. IV. No. 1, 1887) records the following species from the Stockdale Shale series of Wharfe:—

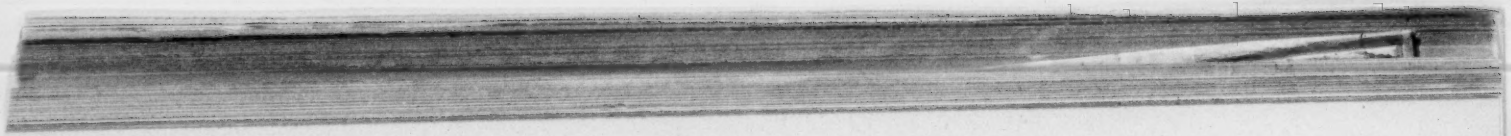
Petraia, sp.
Phacops elegans, Boech and Sars.
Cheirurus bimucronatus, Murch.
Encrinurus punctatus, Emmr.?
Leptæna quinquecostata, McCoy.

To these may be added:—

Illænus, sp.
Encrinurus punctatus. var. *arenaceus*, Salt.
Harpes judex, Marr and Nich.
Staurocephalus, cf. *Murchisoni*, Barr.
Cyphaspis, cf. *rastritum*, Törnq.
Cyphaspis, sp., cf. *Burmeisteri*, Barr.



LOWER PALÆOZOIC FOSSILS FROM YORKSHIRE



Note.—I have to acknowledge my great indebtedness to Mr. Marr for much help in the examination of these obscure fossils.

These fossils are all small, and are generally very poorly preserved. *Encrinurus punctatus*, var. *arenaceus*, fig. 2, is represented by a well preserved glabella with the fixed cheeks attached. Several heads, fig. 3, of *Staurocephalus*, cf. *Murchisoni*, and one tail, fig. 4, were found. *Cyphaspis*, cf. *rastritum*, fig. 6, has at the anterior end of the head a triangular area which extends back and nearly meets the glabella. *Cyphaspis*, sp., cf. *Burmeisteri*, fig. 7, has a very short glabella, less than half as long as the head. *Harpes judex* is represented by a fragment of the limb.

The following species may be added to the list recorded by Mr. Marr, from the Bala beds of Norber Brow :—

Agnostus trinodus, Salt.
Ampyx? *rostratus*, Sars.
Staurocephalus (*Sphærocoryphe*) *unicus*, Thom.
Dindymene Hughesiae, Roberts M S.
? *Ateleocystites*.

The ? *Ateleocystites*, figs. 9 and 10, comes from the Bala beds of Wharfe, the other species are all from those of Norber.

Staurocephalus unicus, fig. 8, is not at all well preserved, but the two prominent spines on the margin are sufficient to distinguish it. An imperfect tail was also found. A specimen of *Dindymene* is recorded by Mr. Marr, and he refers it provisionally to *D. ornata*, Linnars. Mr. Roberts had commenced a description of it, and found it to differ from any species previously described. He proposed to call it *D. Hughesiae* after its discoverer, Mrs. T. McKenny Hughes.

Description of Dindymene Hughesiae.

(PLATE IV. Figs. 1 and 5.)

Length and breadth each somewhat less than an inch. Head occupying about one-third of the total length, semicircular in shape, without cheek-spines. Glabella and cheeks considerably inflated. Glabella much wider in front than behind, separated from cheeks by very deep grooves. Glabella bears two, and each of the cheeks bears one large tubercle. A narrow border extends right round the cheeks, and the whole surface of the glabella and cheeks is minutely granulated. No eyes or facial suture. Thorax with ten segments, each segment of axis marked by a pair of small laterally placed tubercles. Pleuræ greatly prolonged into spines, those of the 3rd, 4th and 5th being longest. Spines of anterior pleuræ form a nearly straight line with proximal parts of pleuræ, spines of the next pleuræ are somewhat curved, and those of the last few pleuræ are bent back nearly parallel to the pygidium. Axis of pygidium less than half as long as thorax, marked by slight furrows, which do not extend completely across it. Pygidium has 3 pairs of pleuræ, all of which are bent back nearly parallel to the axis, while the last pair are nearly in contact with the axis.

D. Hughesiae resembles *D. ornata*, Linnars., but has the following distinguishing characters :—

1. The glabella bears only two well marked tubercles, and these are arranged in a line with the axis.
2. The cheeks each bear a single tubercle.
3. There is no evidence as to the occurrence of cheek spines.
4. The margin of the axis is tuberculate.
5. The pleuræ of the middle thoracic segments are longer than those of the posterior thoracic segments.

D. Hughesiae differs from *D. Frederici Augusti*, Barr., in having two instead of one tubercle on the glabella and one on each cheek, also in having the pleuræ much longer and non-tuberculate.

It differs from *D. Haidingeri*, Barr., which comes decidedly near *D. ornata* in having more tubercles on the glabella and in the greater length of the pleuræ of the middle thoracic segments.

D. Cordai, Eth. and Nich., differs from *D. Hughesiae* in having a pyriform glabella without tubercles.

Note.—I have had to rely only on figures and descriptions in comparing *D. Hughesiae* with the other species.

Note on a Cystidean ? Ateleocystites.

(PLATE IV. Figs. 9 and 10.)

This specimen was found in the Bala beds of Wharfe by Rev. A. Pagan. It is unfortunately not well preserved, but appears to differ considerably from any known cystidean. It appears to belong to the family *Anomalocystidæ* (H. Woodward) and to agree with the other forms figured by Dr. Woodward in the Geol. Mag. 1880, p. 193, in the following characters :—

1. The plates are not arranged with complete regularity.
2. The anterior surface is slightly concave.
3. There are no pectinated rhombs.
4. The plates are marked by a finely wavy ornamentation.

It differs from other *Anomalocystidæ* in the ornamentation of the plates and in the apparent greater irregularity in their arrangement, though this may in part be due to crushing.

The way the arrangement of the plates is to be interpreted is not very clear, but regarding the face preserved as the anterior face, the plates of the upper (oral) surface and right side are well preserved, while those of the left side and lower surface (from which the stem would arise) are more broken. The uppermost median plate is characteristic and is marked by 5 or 6 ridges radiating from a raised point near the margin. All the plates are marked with the wavy lines characteristic of the *Anomalocystidæ*, and in addition are marked by a series of rather deep pits sometimes arranged in lines. These pitted markings are better seen on the impression than on the actual fossil. The markings somewhat resemble those on *Turrilepas*. A segment of the stem is also seen.

EXPLANATION OF PLATE IV.

Fig. 1.—*Dindymene Hughesiae*, Roberts, MS.; pygidium and posterior thoracic segments. × 3½.

,, 2.—*Enerinurus punctatus*, var. *arenaceus*, Salt.; glabella and fixed cheeks. × 6.

,, 3.—*Staurocephalus*, cf. *Murchisoni*, Barr.; part of head. × 6.

FIG. 4.—*Staurocephalus*, cf. *Murchisoni*, Barr.; pygidium. × 6.
,, 5.—*Didymene Hughesiæ*, Roberts, MS.; restored figure. × 3½.
,, 6.—*Cyphaspis*, cf. *Rastritum*, Törnq; fragment of head. × 6.
,, 7.—*Cyphaspis*, sp., cf. *Burmeisteri*, Barr.; fragment of head × 5.
,, 8.—*Staurocephalus* (*Sphærocoryphe*) *unicus*, Thom.; fragment of head. × 5.
,, 9.—? *Ateleocystites*; impression of uppermost median plate. × 1.
,, 10.—? *Ateleocystites*. × 1.

Figures 2, 3, 4, 6, and 7, are from specimens found in the *Phacops elegans* zone = Stockdale shale series (Valentian) of Wharfe, Yorkshire.

Figures 1, 5, and 8 are from specimens found in the Bala beds = Coniston limestone series of Norber brow.

Figures 9 and 10 are from specimens found in the Bala beds = Coniston limestone series of Wharfe.

[The publication of this article has been unavoidably delayed.—EDIT. GEOL. MAG.]

III.—THE RAPE OF THE CHLORITES.

By Lieutenant-General C. A. McMAHON, F.G.S.

I WAS not present when Dr. Callaway's last paper on the Malvern Rocks was read before the Geological Society, and had not the opportunity of joining in the discussion that followed the reading of the paper. The author has now given his views regarding the "Conversion of Chlorite into Biotite" in a condensed form in the GEOLOGICAL MAGAZINE (Dec. 1893, p. 535), and has expressly invited criticism on them; I venture, therefore, in response to this invitation, to give expression to a difficulty that presents itself to my mind.

It is not necessary to enter into a discussion of the authorities quoted by Dr. Callaway; but I remark in passing that two of the papers referred to profess to deal with cases of contact metamorphism, and consequently the conditions that must have prevailed in those cases are altogether different from those which govern Dr. Callaway's supposed case of dynamo-metamorphism. In cases of contact action one can readily understand how aqueous acid vapours, or liquids, emanating from the molten igneous rock under high pressure penetrated the adjoining rocks, and carried with them in solution some of the constituents of the igneous magma.

In the case supposed by Dr. Callaway the conditions are altogether different. We have to deal with a consolidated rock which contains the hydrous mineral chlorite, the anhydrous mineral biotite, and others that show a passage between the two. Dr. Callaway contends that the biotite has not been converted into chlorite by aqueous agencies, but that the hydrous chlorite has been transformed into anhydrous biotite through the action of heat. The fact that the rock contains chlorite as well as biotite, and minerals that show a passage between the two, would seem opposed to the acceptance of the author's view; but he meets this difficulty in the following way:—"The reason why in the Malvern rocks we have sometimes a decomposition of hornblende into chlorite, and sometimes a change of chlorite into biotite, is found in the difference of environment. Where the rock is slightly crushed, and there are no signs of rock-fusion, there is decomposition of hornblende; but where there is intense crushing and shearing, accompanied by a high temperature, reconstruction sets in and biotite is generated."

The heat produced locally by the crushing and shearing of the solid rock, he tell us, "often rose to the point of fusion in the shear zones." What the fusion point was the author does not tell us, but it is obvious that the fusion of rocks, such as those contemplated, must have required a very high temperature.

The intense heat, however, under Dr. Callaway's supposition, was limited to the shear zones and was quite local. In other parts of the same rock, namely those in which chlorite is now to be found, the temperature could not have risen to red heat, for at a red heat, the author tells us, chlorite loses its water.

The author accounts for the escape of water from the altered chlorite, by its having been driven off by heat. The "elimination" of the water from the chlorite, he tells us, offers "no serious difficulty." If so, the rock was, for all practical purposes, a porous rock through which water could be driven by heat.

The conditions supposed to have existed are then briefly as follows: (1) The presence of centres of *intense* heat produced by local crushing and shearing; (2) The existence of temperatures below red heat in other parts of the rock; (3) A porosity in the rock sufficient to allow water to escape from it.

Such being the conditions I am at a loss to understand how the heated chlorite, whilst parting with 12 per cent. of water and 16 per cent. of magnesia, can have acquired 2 per cent. of alumina, 8 per cent. of potash, and 11 per cent. of iron in addition to the alumina and iron already present in it.

The intense heat at the local centres would surely have driven away all the water from those centres to the cooler parts of the rock. The dehydration of the chlorite is accounted for on that supposition. This water, charged, as it probably was, with acid, may have carried away with it the 16 per cent. of magnesia, but by what agency was the additional alumina, potash, and iron conveyed to the chlorites? The water contained in the rock must have been repelled and driven away, as before stated, from the centres of heat. When this water, charged with bases in solution, was moving away from these centres, how could the iron, alumina, and potash in the pores of the rock through which the water passed have forced their way to the distressed chlorites in the face of the bombardment to which they must have been exposed by the panic-stricken molecules rushing away from the centres of disturbance? By what power was the iron, alumina, and potash moved against this stream of fugitives?

I doubt whether, under the conditions supposed, any chlorite would have remained near the centres of heat. Chlorite is readily susceptible to the action of acids; and water, even faintly charged with acids, would, at the high temperature predicated, in all probability have swept all the alumina, iron, and magnesia contained in the chlorites out of these minerals. That the acidified water should have removed 16 per cent. of magnesia and have left the whole of the iron is highly improbable, for, as far as my experience in experiments on minerals goes, I should say that iron is one of the first bases to be removed by acid solvents.

But if we are at liberty to suppose, for the sake of argument, that *none* of the iron, or alumina escaped from the chlorite, what brought the *extra* alumina, potash, and iron to the spot? Why should these bases have left other cooler and more comfortable localities, in which they were located, to force their way to the centres of molecular disturbance where crush, shear, and intense heat prevailed?

If the distressed chlorites had been beautiful females and the iron, potash, and alumina, ardent male creatures one might have accounted for their rushing through fire and smoke to reach these prizes, like Roman soldiers engaged in sacking a town, but I suppose the author is not prepared to endow his molecules with sexual qualities, and, in the absence of any explanation of that kind, I confess that I cannot imagine the nature of the fascination which Dr. Callaway's distressed chlorites appeared to have had for the iron, the potash, and the alumina situated in other parts of the rock; nor can I imagine the agency by which these bases were conveyed from the surrounding rock to the centres of intense heat. These centres were surely the foci of repulsion, not of attraction?

There can have been no flow of water laden with iron, potash, and alumina towards the heated centres, where the chlorites under consideration were, because the author's conditions involve the fact that water was driven away by the intense heat generated at those centres. By what agency then, I ask, was the iron, potash, and alumina divorced from their chemical combinations in other parts of the rock and drawn towards the chlorites?

The author admits that "it is natural that those who have not studied the evidence furnished by the Malvern rocks should adopt an old and well-known explanation of the phenomena in preference to a new and seemingly improbable one"; but surely, if Dr. Callaway asks those who have not studied the Malvern rocks to believe the "seemingly improbable theory" which he advocates in preference to a more obvious one, it is incumbent on him to explain in detail by what agency the molecular movements involved in his theory were brought about. Dr. Callaway remarks that "if this mineral transformation be an observed fact, it may seem unnecessary to discuss theoretical objections to it"; but the conversion of chlorite into biotite does not yet rank as an "observed fact." The only observed fact is that chlorite and biotite have been found in the same rock. Dr. Callaway offers a theory to account for this fact. Those who doubt the correctness of this theory have a right to ask for full proof of its genuineness before it is stamped with the Hall mark. I desire to offer one more remark in conclusion.

Dr. Callaway tells us that "the temperature of metamorphism in the Malvern rocks often rose to the point of fusion.". If so, actual fusion must have been the result, and biotite cannot, in those localities, have been formed at the "expense of chlorite," for all the chlorite would have been melted down and would have been merged in the fused and fluid magma. If, on cooling, biotite crystallized out of this magma it would have been at the "expense" of the general

fund of bases, and not at the expense of the chlorite. Moreover, the fused rock, unless it were subjected to shearing, or fluxion, in a partially crystallized condition, would have consolidated as a granite, not as a gneiss; and would have exhibited a granitic and not a foliated or gneissic structure.

[The Editor regrets that owing to the pressure on the space of the MAGAZINE, the publication of this article has been unavoidably delayed.—EDIT. GEOL. MAG.]

IV.—SOME NOTES ON GNEISS.[1]

By Professor T. G. BONNEY, D.Sc., LL.D., F.R.S.

MUCH light has been thrown of late years on the history of gneiss and other foliated rocks. Geological literature is beginning to bristle with such terms as regional-metamorphism, pressure-metamorphism, dynamo-metamorphism, and the like. Yet longer and less intelligible names will probably follow, which, under the guise of precision, will foster confusion. So it may be a little help to students to set down, as far as possible in plain English, the fruits of some years' study of gneisses and allied rocks. In this work I have taken nothing on trust, and have tested every inference to the best of my ability. Probably there is nothing original in the results, but they are all the outcome of personal observation, for I have always preferred questioning Nature to reading books. So, in order to economize time in searching for what has been already said, and to save studding the page with references, I will assure the reader that he is quite at liberty to suppose that "everything has been said by somebody, somewhere."

Let us begin our observations with a rock which is a fairly coarse granite, occurring in a region affected by great earth-movements, such as mountain-making, which, however, for some reason or other, has escaped with its structure practically unmodified. Such a rock sometimes may be locally indistinguishable from an ordinary granite, but very commonly a small difference is perceptible, especially on a slightly weathered surface. This has a rather fragmental aspect, the quartz and the felspar presenting a superficial resemblance to unrolled clastic grains,—as in an arkose, the materials of which have been transported only for a short distance. This resemblance does not disappear on microscopic examination. The rock, in short, has been fractured but not crushed. This structure is exhibited (not to mention other examples) locally in the granite at the entrance of the Val Rosegg (Pontresina), in the granitoid rock of Twt Hill (Carnarvon), and of Llanfaelog (Anglesey); occasionally also in the so-called Dimetian of St. Davids. This, then, may be regarded as the first stage in pressure-modification.

Next suppose this agent to have produced more marked effects, and the rock to have been definitely crushed, perhaps also slightly

[1] It may be well to state that this paper was written some time prior to the publication of Mr. Goodchild's paper in the January Number of this MAGAZINE, and has been left unaltered.

"sheared" in addition. I have more than once described the results of such a process,[1] so far as the different minerals are concerned; hence it is needless to enter into details, and I shall confine myself to a few general illustrations of the making of a gneiss by pressure.

To exhibit the first stage we may select a porphyritic granite from near the English church at Saas Fee (Valais). The rock might be termed an "augen-gneiss." If, however, a surface transverse to the foliation be examined, the felspar crystals are fairly regular in shape, being only a little distorted or rounded at the angles, and are not conspicuously orientated. But on a surface in the direction of the foliation they appear as rather irregular, wavy streaks, parted by streaks and lines of dark mica. The annexed sketch (Fig. 1) shows

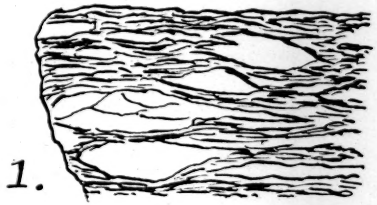


Fig. 1.—Augen-gneiss, near Saas Fee, section along the "dip plane" of the foliation (the rock near the church is a little less crushed than this, but my sketch is rather too rough to be copied).

a slightly more advanced stage of the same rock. The larger felspar crystals vary from lenticular to streaky in form, are sometimes cracked and slightly separated, as is indicated by lines of dark mica about the thickness of a sheet of writing-paper. The smaller felspars have been often crushed almost to powder.

A stage somewhat more advanced may be found in gneiss (common in boulders) on the eastern bank of the Davoser See. Here the rock hardly can be called an augen-gneiss, for generally it is a coarse, streaky, slightly wavy, foliated gneiss—constituent minerals: quartz, felspar, biotite and some white mica. But on close examination traces of the original structure can be detected, as is shown in the annexed sketch (Fig. 2), and from this stage a gradual transition

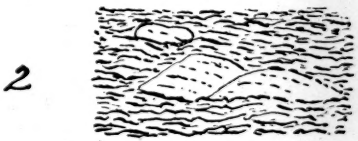


Fig. 2.—Remains of crystals in a much crushed augen-gneiss, near Davos Dörfli.

can be traced backwards into a true augen-gneiss, in which the white rounded felspars are over 2″ in diameter.

[1] See Presidential Address, Quart. Journ. Geol. Soc. 1886, Proc. 67, 68.

Further crushing, associated with definite shearing, at last practically obliterates all distinct traces of "augen" structure. The streaks of different mineral composition, the more quartzo-felspathic and the more micaceous, especially the latter, become longer and thinner, until, as the ultimate result, we come to a fine banded rock, with laminæ so uniform as to suggest that the materials once were stratified. Excellent illustrations of this may be found in a number of large boulders strewn about the lower end of the St. Moritz lake. One block may be a rather coarse granitoid gneiss, the quartz, felspar and mica (especially) forming little streaks. Another affords a rock more markedly fissile, the surface of the slabs being slightly undulate and of a sage-green colour (from the crushed and hydrated biotite or from secondary chlorite). Slight streaks of white here and there show through the "varnish," which is very thin: that is, through the film of secondary mica forming the "sheen surface." But on examining the transversely fractured ends of slabs, we see white wavy streaks of quartz and felspar, perhaps a couple of inches long and a fifth of an inch broad at the thickest part, from which condition we are led on to a still more fissile rock, composed of alternating laminæ of white and green: the former about one-eighth of an inch thick, the latter still thinner, each of which may be traced for a length, usually, of from three to four inches; these bands, it is important to notice, not being continuous through the block. In certain extreme cases the rock is more like a mica-schist than a gneiss, but even then very thin white streaks may be detected on examining a transverse fracture. The Central Oberland and some parts of the Pennines afford many like instances. This "linear foliation" seems to be the utmost that crushing and shearing can produce, and the latter is an essential factor. To obtain this structure the rock must be granitoid and fairly coarse; where it has been also porphyritic, that probably is recorded by a little irregularity in the linear foliation, *i.e.* the occasional presence of slightly thicker and more lenticular streaks. The more regularly "lined" varieties have come, I believe, from rather coarse but non-porphyritic rocks. The more close the resemblance to a mica-schist, the more complete, in all probability, the crushing. In these cases it may be also necessary that the rock originally was rather fine-grained.

Analogous structures may be produced in more basic rocks, such as diorites and dolerites, but in them mineral changes seem to take place more easily, such as the formation of acicular hornblende, chlorite, epidote, and secondary felspar. These I have elsewhere described, so that I may sum up the result of at least ten years of study in the following statement: That pressure is a potent factor in structural and mineral change in granitoid rocks, whether acid or basic, though more so in the latter than in the former; that the resulting structures pass through a somewhat wavy or lenticular streaking to a thin banding, which may ultimately lead to an almost slate-like fissility; but that I have never found any reason to suppose that a well-marked mineral banding, such as one in which

the layers may exceed a quarter of an inch in thickness, can be produced by pressure acting on a rock in which no such structure originally existed.

But there are many gneisses which are distinctly and broadly banded. Such, for instance, occur among the Laurentian rocks of Canada and Greenland, the "Hebridean" rocks of Scotland, the ancient crystalline rocks of Norway, and those of several parts of the Alps. As an example I may refer to a gneiss in the neigbourhood of Saas Fee. A huge boulder, which in all probability came from the lower part of the Mittaghorn, afforded the particular instance. The rock consists of quartz, felspar, and a greenish-grey mica, and is rather fine-grained. The banded structure is very distinct, the lighter zones consisting chiefly of quartz and felspar with small flakes of mica, the darker being richer in mica, which

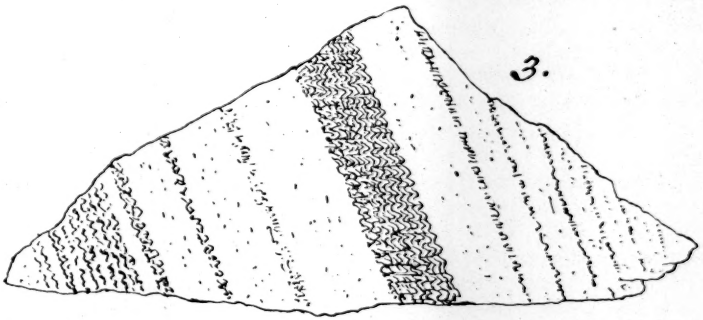


Fig. 3.—Gneiss with "rucking" and traces of strain-slip cleavage in the broadest micaceous band. Fragment about 15″ long, from part of a fallen block, near Saas Fee.

occurs also in larger flakes (Fig. 3). The former are usually the thicker; the latter vary from between two and three inches in thickness to little more than films. In these the mica flakes are bent into zigzags, and in the broader bands a strain-slip cleavage sometimes may be seen crossing them obliquely. This structure, the result of pressure, is clearly later than the formation of the bands.

As another example a boulder may be cited which I found lying on the flank of the Schafberg at Pontresina. In this also—a fairly coarse gneiss—the mineral banding is distinct, the broadest of the more micaceous zones being nearly three inches across. But in addition to this the whole block shows an oblique "lamination" of more or less micaceous stratulæ, even in the more quartzo-felspathic bands. This structure, which is not very uncommon, curiously resembles current-bedding in a stratified rock, to which, indeed, it has been referred by more than one well-qualified observer. Formerly I should have so regarded it myself, but I am now convinced that the resemblance is illusory and that it is a result of pressure.[1]

A third example may be mentioned, because it may require a dif-

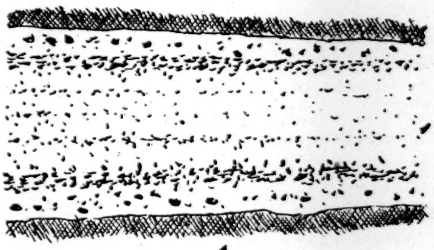
[1] *See* Quart. Journ. Geol. Soc. Proc. 1886, p. 97.

ferent explanation. This occurs on the south side of the St. Gothard Pass, about 1900 feet above Airolo, where the road between two bridges is nearly level, and about a furlong from the foot of the second set of zigzags.

The dominant rock is a dark biotite schist, but it is locally interbanded with a light-grey granulitic rock. The latter varies from mere lines to bands one or two inches thick, which, however, are rather impersistent, thickening or thinning or splitting, generally in the course of two or three feet, and stopping sometimes with a moderately pointed end. Of this last case two explanations seem possible: the structure may be original and "fluxional" in origin, produced by a partial melting of the darker rock in consequence of the intrusion of the lighter one, the two then moving on together; or it may be due to the crushing of a solid mass, in which the one rock formed veins in the other. I have examined, however, a good many cases in which a "veined" mass has been crushed and somewhat sheared, and, while I cannot deny that this explanation is a possible one here, I feel bound to remark that, if so, the case is a rather exceptional one. But it seems to me impossible thus to explain either the first two cases or the very numerous instances of banded gneisses which I have seen in many lands and extending over large areas. In regard to these, as it appears to me, we must choose between two hypotheses: that of fluxional movements anterior to complete consolidation in a mass not perfectly homogeneous, and that of the metamorphism of a stratified rock. For reasons which I will state presently, I think the latter to be only rarely applicable, and the former to be generally the correct one. This, as has been shown in papers already published,[1] must be the origin of some banded gneisses in Sark,[2] and (we may perhaps add) at the Lizard. Fluxional structure undoubtedly, as I believe, sometimes occurs in the gabbro of the Lizard Peninsula,[3] and of the Saas valley,[4] in the diorites of Guernsey, and in the dolerite of Mount Royal (Canada). Most of these instances of mineral banding are afforded by districts on which pressure has not produced any marked effects. Some rocks at the Lizard certainly show pressure-metamorphism, but not in the vicinity of the banded gabbros, where the serpentine in which they are intruded is practically undisturbed, and even in the Alps the tough gabbros have not seldom succeeded in resisting it. Still, as some persons are sceptical on this matter, it may be interesting to add another case where veins of intrusive granite exhibit a well-banded structure which cannot be explained by anything but a movement of the material while still in a plastic condition. This may be found in a mass of ice-worn rock near the base of the Allalin glacier. Granite veins, generally narrow, break in all directions through a mass of greenish schist (the *Grüner schiefer* of the Swiss geologists), apparently not having any necessary connection with the foliation, which is conspicuous in the latter and is probably the result of pressure. This, however, cannot have pro-

[1] Quart. Journ. Geol. Soc. 1892, p. 122.
[2] *Ibid* 1891, p. 464.
[3] *Loc. cit.* p. 483.
[4] Phil. Mag. 1892, p. 237.

duced the structure of the granite, which is roughly parallel with the sides of the veins, and thus inconstant in direction. The granite is moderately fine-grained, consisting of quartz and felspar, with only a little white mica. Taking one vein, about six inches wide, as an example (Fig. 4), we find the outer band (rather more than one inch thick) somewhat more coarse-grained than the rest, the felspar varying in size from large hemp-seeds to very small peas. The next band is richer in quartz; the interior differs somewhat from both and



4.

Fig 4.—Vein of streaky and banded granite intrusion in green-schist. Rock near the foot of the Allalin glacier. Diagrammatic, the spots indicating the more conspicuous felspar-grains.

seems to exhibit a slight fluxional structure. Parts of some of the veins were rather more micaceous, that mineral also occurring in streaks, sometimes apparently connected with small inclusions of the green schist. The banding may be very clear for three or four feet, then may become less distinct; one vein may show it, another not. A movement of the constituents where the mass was not yet perfectly consolidated is rendered probable by the rounded form of the felspars, and this hypothesis alone seems possible as an explanation of the banding.

In regions such as the Alps, which have been more than once affected by great earth movements, there is always a possibility that after a structure had been produced by one set of disturbances, the mass in the lapse of time might become completely consolidated—perfectly cemented as it were, by secondary mineral deposits—after which it might be modified by a new set of earth movements. This, very possibly, may be the history of certain banded gneisses, generally rather fine grained, in which the layers of mica, though very regular, are quite thin—hardly thicker than a stout piece of cardboard; such, for instance, as the rather fine-grained gneiss which occurs on the east coast of Scotland about and to the north of Muchals. But I have never been able to find any proof of the notion that a broad banding can be produced by any amount of crushing in an ordinary holocrystalline rock, while I have demonstrated, as I venture to think, that it can come from movements anterior to the consolidation of the mass; so that while we may admit the possibility of the former explanation being true for a certain group

of rocks in which the bands of mica or of other minerals are thin, we must deny it in all cases where they are even moderately thick.

But was the old notion entirely wrong? Cannot a gneiss be in any case an altered sedimentary rock? Beyond all doubt not a few schists have thus originated: all calc-schists and quartz-schists; many mica-schists; perhaps also some hornblendic and chloritic schists. I am aware that it has been suggested that certain basic rocks might be changed into calc-schists. It is true a hornblendite or a pyroxenite might produce an ophicalcite, but both these are rare rocks; also certain calc-mica schists might come from rocks of the doleritic group; but I doubt whether we have evidence of such transmuting power as would produce on the one hand anything like a marble or one of the purer calc-schists, on the other a rock so siliceous as certain quartz-schists. They are interbedded and associated; they alternate with and graduate into one another, now rapidly, now slowly; they present macroscopic resemblances to stratification, even more perfectly than the examples which we have considered above, while, in the case of not a few, the possibility of an igneous origin is excluded by their mineral composition. There seems, however, no reason why a sediment of the proper chemical composition should not, as a result of metamorphic processes, be changed into a gneiss. But, as a rule, clays (for to some variety of this rock we must look) are rather deficient in alkalies, and seem to produce micas and minerals such as andalusite more readily than felspar.

In cases of contact alteration, though felspar occurs more frequently than has been supposed, it seems not to be very common; while pressure appears to bring about the conversion of felspar, where it already exists, into quartz and white mica. Into these minerals, indeed, it sometimes appears to break up without any such disturbing cause.[1] No doubt felspar of secondary origin is a more common constituent of crystalline schists than has hitherto been supposed, and the mineral has been often overlooked in consequence of the close resemblance to quartz which this variety presents, but this fact, so far as our present knowledge goes, is more applicable to the products of basic than of acid igneous rocks, and does not seem likely to remove our difficulties in the case of gneisses.

It is not, however, possible for a rock like the Torridon sandstone to be reconsolidated by secondary enlargment of its constituent grains, and to pass back, as do some quartzites, into a really crystalline condition; thus producing a rock similar to one of the Laurentian gneisses? Such a change would be theoretically possible, but it is not easy to find satisfactory evidence that it has really occurred. The Torridon sandstone of Scotland, the *grès felspathique* of Normandy, where they have been subjected to pressure, approach nearer to the mica-schist group, the felspar disappearing in the manner already mentioned. I have not myself seen any marked case of contact-metamorphism in either of these rocks, so that I cannot be certain what would be the effects of raising them to a fairly high temperature under moderate pressure and in the presence

[1] Quart. Journ. Geol. Soc. 1888, p. 36.

of water. Of course cases can be found where a gneiss is *imitated*, such as the so-called Carboniferous gneiss of Guttannen.[1] Here, however, the rock has not been restored, in any proper sense of the word, to a crystalline condition; it is only a somewhat consolidated "arkose" like the Torridon sandstone, which also has been slightly modified by subsequent pressure. Hence it has no more claim to the name of gneiss than certain very remarkable specimens of the Torridon rock have to that of granite. Pebbles of this rock (or of one exactly like it) sometimes so closely resemble granite that I have found it necessary to examine them under the microscope before I could feel satisfied as to their clastic character. In such cases as these Nature has been perpetrating a forgery and setting a trap for unwary geologists.

Still, notwithstanding these difficulties, I think it would be rash, in the present state of our knowledge, to deny the possibility of gneiss being produced by the alteration of a sedimentary rock. Among certain quartz-schists (not quartzites) I have occasionally found interstratified bands or beds, including grains of felspar, for which it seemed as reasonable to infer a clastic origin as for the other constituents—that is to say, they were probably enlargements of a fragment of felspar. This mineral occasionally is sufficiently abundant to make the rock petrographically a quartzose gneiss. With direct evidence such as this, and the indirect evidence afforded by the formation of secondary felspar in certain cases of contact-metamorphism and in some crystalline schists, it would be unwise to deny the possibility of gneiss having been formed by the metamorphism of a sedimentary rock. Still, I think this origin will prove to be a rather exceptional one, and the masses produced comparatively thin and limited in extent.

We conclude, therefore, that the term gneiss covers a group of rocks rather different in character and very different in history. One (a common type) is a gneiss in consequence of an original structure, and remains very nearly in its original condition. Another (also common) owes its structure to pressure acting on a rock which had already solidified and had become crystalline. A third (probably rather rare and exceptional) is the result of the metamorphism of materials which were originally clastic. It is very probable that each of these groups will be found to possess distinctive structures: to some of them I have already invited attention; others will doubtless be discovered during the next few years. The enquiry is as promising as it is interesting and success is probable, if the investigators remember that work in the field must go hand in hand with the study of structures under the microscope. These methods, when united, may be fertile, but when dissociated they can only result in a false conception and a bringing forth of wind.

[1] Quart. Journ. Geol. Soc. 1892, p. 390.

V.—Notes on the Skiddaw Slates.

By J. E. Marr, M.A., F.R.S., Sec.G.S.

THE Woodwardian Museum has for many years contained a fine series of Skiddaw Slate fossils. In 1890 this was increased by the addition of many specimens obtained by the members of Prof. Hughes' Long Vacation party, and immediately afterwards the University acquired, by donation, the valuable collection of the late Mr. Kinsey Dover. Prof. Nicholson has also presented a large number of Graptolites. When time permits, I hope to be able to describe our unrivalled collection of Skiddaw Slate fossils; meanwhile, a few notes on the distribution of these organisms will throw such light on the development of the Skiddaw Slates as is required for the elucidation of the detailed structure of the district, a task which Mr. Harker and I shall attempt to perform ere long.

For a considerable period the Skiddaw Slates were unhesitatingly correlated with the Arenig rocks of North Wales. The late Mr. Clifton Ward was the first to return to the opinion, long ago formed by Sedgwick, that representatives of much older deposits might occur amongst these slates. In the volume of this Magazine for 1879[1] he remarks: "The physical evidence inclines one to believe that the Skiddaw Slates include the Arenig Slates, the Arenig Grit, the Tremadoc Slates, and the Lingula Flags." Mr. Ward drew up his subdivisions almost entirely on physical evidence, and, indeed, treated (as was customary at the time) the evidence yielded by the Graptolites as of little practical utility. A study of these Graptolites shows that he was quite correct in his view that the slates were not entirely formed during Arenig times, but the actual divisions which he proposed, as shown in the map and sections accompanying his paper and in the explanations thereof, do not stand the palæontological test.

The term "Skiddaw Slates" has been used for all sedimentary and contemporaneous volcanic deposits of the Lake District and neighbourhood which lie below the great volcanic group known as the Borrowdale Series, and in that sense it will be used in this paper, though no attempt will be here made to discuss the character of the junction between the two groups at different places.

Although the general use of the term has been as above, nevertheless other deposits, which are undoubtedly of very different age, have been at times included in the Skiddaw Slates, as, for instance, the Drygill Shales, described by Prof. Nicholson and myself in this Magazine.[2]

The main outcrop of the Skiddaw Slates lies north of the mass of volcanic rocks constituting the central hills of Cumbria, and, owing to the existence of an anticlinal fold, separates those volcanic rocks from their equivalents in the Caldbeck Fells and the comparatively low country north of Bassenthwaite Lake. This outcrop appears to be continuous (though in one place covered by the Carboniferous con-

[1] Geol. Mag. 1879, Dec. II. Vol. VI. p. 124.
[2] Geol. Mag. 1887, Dec. III. Vol. IV. p. 339.

glomerate near Ulleswater) with that of the Skiddaw Slates, ranging in a N.N.W—S.S.E. direction, from the east side of Saddleback to the neighbourhood of Shap, across the eastern extremity of Ulleswater. Another mass of Skiddaw Slate forms the prominent hill of Black Comb at the southern end of Cumberland, and a subsidiary outcrop occurs near Dalton-in-Furness. A large part of the Isle of Man is also occupied by Skiddaw Slates. To the east of the Lake District beds referred to these slates are found in the Cross Fell Inlier, and are mapped by the Geological Surveyors in the small inlier of Teesdale; and it has been suggested by Mr. Aveline that a portion of the green slates of Ingleton is referable to this group.

The general characters of the Skiddaw Slates have been frequently described. Almost every variety of arenaceous and argillaceous deposit may be found, besides volcanic ashes and lavas. They are distinguished by a general absence of calcareous matter. The Graptolites, which it is the object of the writer to consider more particularly, are generally found in, though by no means universally confined to, the black or blue-grey argillaceous members of the group. These Graptolitiferous argillaceous rocks may be frequently traced in bands running parallel with the general strike of the rocks, and extending for a greater or less distance in this direction. They have been largely worked by local observers, especially by the late Mr. Kinsey Dover and Mr. Postlethwaite in the neighbourhood of Keswick, the result being that our richest collections have been gathered from the vicinity of that town: and many localities away from it, which are rendered classical by the work of the earlier exponents of the palæontology of the Skiddaw Slates,—Salter, Harkness, Nicholson, and others, still require much examination before their faunas can be considered thoroughly known.

The following list of Graptolites, compiled from the Woodwardian Collection, the writings of various authors, notably Nicholson, and, after brief examination of the collection of Mr. Postlethwaite and that in the Keswick Museum, will be sufficient to allow us to draw important conclusions:—

List of Graptolites from the Skiddaw Slates.

Didymograptus affinis, Nich. Barf; Carlside Edge; Eggbeck; Ellergill.
,, *bifidus*, Hall. Outerside; E. of Dodd Wood, Keswick; Doddick Fell, Saddleback; Eggbeck; Ellergill.
,, *indentus* var. *nanus*, Lapw. Outerside; Barf; Gategill, Saddleback; Glenderamakin Valley, Mungrisdale; Thornship Beck.
,, *Murchisoni*, Boeck. Outerside; Thornship Beck; Cross Fell area.
,, *fasciculatus*, Nich. Eggbeck; Thornship Beck; Ellergill.
,, *gibberulus*, Nich. Randal Crag; White Horse, N.W. of Skiddaw.
,, *Nicholsoni*, Lapw. Outerside; Barf; Carlside; Thornship Beck.
,, *nitidus*, Hall. Barf; Randal Crag; Knott Head, Whinlatter Pass; Brundelhow Lead Mine.
,, *patulus*, Hall. Outerside; Randal Crag; Eggbeck.
,, V. *fractus*, Salt. Barf; Dodd, Brackenthwaite; New Brow Quarry, Upper Lorton.
,, V. *fractus*, var. *volucer*, H. O. Nich. Outerside.
,, *extensus*, Hall. Outerside; Randal Crag; Knockmurton, near Lamplugh Cross.

Azygograptus Lapworthi, Nich. Barf; N.E. of Sleet How, W. of Braithwaite; Hodgson How; Carlside Edge.
,, *cælebs*, Lapw. Ellergill.
Janograptus? sp. Brunstock Scar, below Randal Crag.
Tetragraptus Bigsbyi, Hall. Outerside; White Horse Fell; Great Knott, Randal Crag; Bassenthwaite Sand Beds; Gibraltar, Skiddaw (in chiastolite slate).
Tetragraptus bryonoides, Hall. Outerside; Barf; Randal Crag; White Horse Fell; Frozen Gill.
,, *quadribrachiatus*, Hall. Outerside; Scale Hill, Crummock; Aiken Gill (Seawgill); N.E. of Grizedale Pike; Carlside Edge; Barf.
,, *Headi*, Hall. Barf; S. end of Randal Crag.
,, *crucifer*, Hall. Barf.
,, *fruticosus*, Hall. (Recorded by Lapworth.)
Dichograptus Sedgwicki, Salt. Braithwaite; Mire House, near Skiddaw.
,, *octobrachiatus*, Hall. Outerside; Carlside Edge; Slape Crags above Hole Gill, Brackenthwaite.
,, n. sp. Outerside.
Loganograptus Logani, Hall. Outerside; Barf; Randal Crag.
Trichograptus gracilis, Nich. Thornship Beck; Ashlock Sike?
Temnograptus multiplex, Nich. Near Peelwyke (not *in situ*); New Brow Quarry, Upper Lorton; How, Scale Hill.
Schizograptus reticulatus, Nich. Barf; Carlside Edge; Scale Hill.
Trochograptus? vagans, Nich. Scale Hill.
Bryograptus ramosus, Brögger. Barf.
,, *Callavei*, Lapw.? Barf.
Phyllograptus typus, Hall. Barf; Whiteside; Carlside; E. of Dodd Wood; Randal Crag; Glenderamakin Valley, Mungrisdale.
Phyllograptus Anna, Hall. Randal Crag.
,, *angustifolius*, Hall. Barf; Carlside; Whiteside; Bassenthwaite Sand Beds; Knott Head, Whinlatter; Ellergill.
,, *ilicifolius*, Hall. N.E. of Sleet How, W. of Braithwaite.
Diplograptus dentatus, Hall. Outerside; Bassenthwaite Sand Beds; N.W. of Lingside, Skiddaw; Glenderamakin Valley, Mungrisdale; Ellergill; Master Sike, Cross Fell area.
Climacograptus. Outerside; Ellergill.
Cryptograptus? Hopkinsoni, Nich. Outerside; Thornship Beck.
,, ? *antennarius*, Hall. Outerside; Glenderamakin Valley, Mungrisdale.
,, *tricornis*, Carr. Outerside; Ellergill.
Glossograptus armatus, Nich. Thornship Beck.
Trigonograptus ensiformis, Hall. Mosedale, near Troutbeck.
,, *lanceolatus*, Nich. Ellergill.
Dicellograptus moffatensis, Carr.? Barf; Randal Crag; Bassenthwaite Sand Beds.
Ctenograptus annulatus, Nich. Barrow, near Braithwaite; Wath Brow, near Keswick.
Thamnograptus Doveri, Nich. S.W. of Randal Crag.

So many fossils which are elsewhere considered characteristic of different horizons occur in the same locality, *e.g.* at Barf and at Outerside, and the same species recur with such frequency in strata which appear to be at different horizons, that the attempt to divide the Skiddaw Slates into different fossil zones seems at first sight impossible. Amidst rocks so contorted as the Skiddaw Slates, the lesson taught by the convoluted rocks of the Southern Uplands of Scotland must not be forgotten, and a careful study of the list above given in the light gained by examination of other areas proves the zonal classification of the rocks to be applicable here. At the same time, owing to the difficulty of obtaining good specimens *in situ* (a large number of the specimens in collections having been gathered from the loose *débris* or screes on the sides of hills) any

attempt to map the Skiddaw Slates according to their zones will be fraught with unusual difficulty, and can only be accomplished by a local observer with much time at his disposal through a term of many years. Even then, the work will hardly repay the labour, for the zonal succession of the equivalents of the Skiddaw Slates will doubtless be discovered in other areas, where the slighter disturbance of the rocks will render the task one of comparative simplicity. This being the case we may at once proceed to discover what may be learnt from an examination of our present list.

In studying it we may gain much information from noticing the species which occur together on the same slab of stone (see p. 130), and also by observing what species are absent from particular localities.

In Prof. Lapworth's paper on the Geological Distribution of the Rhabdophora [1] the Skiddaw Slates are divided into an Upper and a Lower Group, but we require still further sub-divisions. These sub-divisions will be considered in order, beginning with the oldest beds.

1. Tremadoc Beds.

Bryograptus Beds.—In Mr. Postlethwaite's collection is a slab (see p. 130), of black slate from Barf, covered with numerous specimens of *Bryograptus ramosus*, Brögger. The slab is shown natural size in Fig. 1, p. 130, whilst Fig. 2, is a representation of one of the Graptolites upon it enlarged two diameters. Another slab was discovered by Miss Serjeant, of Girton College, at the same place, and is now in the Woodwardian Museum. It bears fewer Graptolites, but they are in a better state of preservation. Fig. 3, shows the proximal portion of one of the Graptolites with a filiform process from the proximal end of the sicula, whilst Fig. 4, represents another Graptolite from the same slab, which is further enlarged in Fig. 5, to exhibit the impression of the virgula. The Graptolite figured by Salter [2] under the name "Branchlet of *Dichograpsus*" appears to belong to this species.

A specimen collected at Barf by Mr. E. H. Tetley, of Trinity College, and delineated in Fig. 6, possesses the characters of *Bryograptus Callavei*, Lapw. The specimen is incomplete, and shows fragments of four stipes only, but there is little doubt that it is referable to this form.

These specimens indicate the Tremadoc age of the beds containing them, for *Bryograptus* does not occur above this horizon.[3] In Norway *Bryograptus ramosus* is found low down amongst the representatives of the Tremadoc Slates, in the Lower Division of the Ceratopygeschiefer, whilst *Bryograptus Callavei* occurs in the Tremadoc Beds of the Shineton area.

Bryograptus is not found associated with any other Graptolite on the same slab in the Skiddaw Slates. Had it existed with the

[1] Ann. and Mag. Nat. Hist. ser. 5. vol. iii.

[2] Quart. Journ. Geol. Soc. vol. xix. p. 137, fig. 12.

[3] *Tetragraptus fruticosus* of Hall, with only four stipes, has no claim to be included in the genus *Bryograptus*.

ordinary Arenig Graptolites of the area, it could hardly have escaped detection, for it must have been far from rare considering the large numbers observable on the two slabs which I have seen, and slabs with Arenig Graptolites have been collected by hundreds.

It is possible that some of the other compound branching Graptolites of the Skiddaw Slates may also be of Tremadoc age. Some forms have been doubtfully referred to *Clonograptus*, which occurs in Tremadoc rocks, but none which I have seen are specifically identical with Tremadoc species, and it is doubtful whether any of the forms are truly referable to the genus.

2. Arenig-Llanvirn Beds.

A. *Dichograptus Beds.*—The evidence upon which these beds are separated from the newer *Tetragraptus* Beds is unfortunately of a negative character, though the cumulative evidence is fairly convincing. In the first place, the general rule appears to be for the more numerously-branched forms of *Dichograptidæ* to occur in earlier beds than those with fewer stipes. When the evolution of the *Dichograptidæ* is worked out in full, I have no doubt that the reason for this will become evident. Again, *Dichograptus*, *Loganograptus* and *Temnograptus* are never found in association with the *Tetragrapti* of the Skiddaw Slates, *i.e.* upon the same slab. Lastly, there are areas where *Tetragraptus* is found in which *Dichograptus* does not occur, *e.g.* in the Arenig rocks of South Wales and the Bennane shales of the Ballantrae District[1]: as *Dichograptus* and *Loganograptus* are widely distributed forms, this would hardly be the case if they existed at the same time, and the probability is that the *Dichograptus* Beds are not represented, or have not been discovered, or are represented by non-Graptolitic Beds in South Wales and South Scotland.

B. *Tetragraptus Beds.*—These beds contain by far the larger proportion of Graptolites which have been obtained from the Skiddaw Slates. In the list of Graptolites above given, all the species of *Tetragraptus*, *Phyllograptus*, *Didymograptus*, *Azygograptus*, etc., which have other localities assigned to them than those on which Ellergill Beds only occur, are found in the *Tetragraptus* Beds. Of the Graptolites appertaining to this horizon—

Tetragraptus bryonoides occurs on the same slab as *T. Bigsbyi*.
" " occurs on the same slab as *Didymograptus gibberulus*.
" *Bigsbyi* occurs on the same slab as *Didymograptus indentus* var. *nanus*.
" *bryonoides* occurs on the same slab as *Phyllograptus typus*.
" *quadribrachiatus* occurs on the same slab as *Didymograptus nitidus*.
" " occurs on the same slab as *T. crucifer*
Didymograptus nitidus occurs on the same slab as *Dicellograptus moffatensis*.

The Graptolites of this division are usually preserved in black slates, but others are found in slates of a lighter colour, or even in light-coloured gritty shales.

The *Tetragraptus* Beds are probably divisible into sub-zones. For instance, *Azygograptus Lapworthi* occurs in great abundance in

[1] *Cf.* Lapworth and Hopkinson, Quart. Journ. Geol. Soc. vol. xxxi. p. 631; and Lapworth, Geol. Mag. Dec. III. Vol. VI. p. 22.

leaden-grey gritty shales, and these shales are probably restricted to some definite horizon in the *Tetragraptus* Beds, but we have no evidence as to the exact position of that horizon. The further occurrence of *Azygograptus* in the Ellergill Beds suggests a fairly high position for the grits with *Azygograptus Lapworthi.*

Black shales with *Didymograptus indentus,* var. *nanus,* in profusion form a marked feature of these beds. They are often traceable for a considerable distance along the line of strike. The presence of these tuning-fork *Didymograpti,* which are elsewhere so characteristic of Upper Arenig and Lower Llandeilo strata, indicates that the *Didymograptus nanus* Beds form the upper division of the *Tetragraptus* Beds, which may, therefore, be divided into (1) Lower *Tetragraptus* Beds and (2) Upper *Tetragraptus* Beds, with abundance of *Didymograptus nanus.* An examination of the Graptolites associated with *Didymograptus nanus* near Mungrisdale bears out this view.

The *Tetragraptus* Beds and the overlying Ellergill Beds contain the greatest number of Trilobites hitherto discovered in the Skiddaw Slates. Most of these Trilobites belong to the "Llanvirn" fauna. I hope to refer to them at greater length in another communication.

3. Ellergill Beds.

These beds are usually recognizable with ease by their peculiar earthy nature. Their fauna is also different from that of the underlying rocks, and indicates a very high position in the Arenig Series. They are typically developed at Ellergill, Knock Ore Gill, and Ashlock Sike in the Cross Fell Area, at Thornship and Keld Becks near Shap, and in the moory country near Troutbeck Station, extending towards Threlkeld. Amongst the Graptolites which have been found in these beds are:—

Didymograptus affinis, Nich.
,, *bifidus,* Hall.
,, *indentus,* var. *nanus,* Lapw.
,, *Murchisoni,* Beck.
† ,, *fasciculatus,* Nich.
,, *Nicholsoni,* Lapw.
† *Azygograptus cælebs,* Lapw.
† *Trichograptus gracilis,* Nich.
Phyllograptus angustifolius, Hall.
Diplograptus dentatus, Hall.
Climacograptus.
Cryptograptus ? Hopkinsoni, Lapw.
,, *tricornis,* Carr.
† *Glossograptus armatus,* Nich.
† *Trigonograptus ensiformis,* Hall.
† ,, *lanceolatus,* Nich.

Those marked † have hitherto been found only in this division of the Skiddaw Slates.

4. Milburn Beds.

Mr. Goodchild has applied this name to certain slates interstratified with volcanic rocks, which in the Cross Fell area appear to form a passage between the Skiddaw Slates and the volcanic series of Borrowdale. Similar beds occur in many parts of the Lake

District. Unfortunately their fauna is almost unknown, *Didymograptus Murchisoni* and *Diplograptus dentatus* being the only fossils hitherto recorded from them. They probably represent the uppermost part of the Arenig or the lowermost part of the Llandeilo formation. It is to be hoped that local observers will pay special attention to the fauna of these beds, as the exact determination of their age is a matter of considerable importance.

From a study of the Skiddaw Graptolites, then, we obtain the following provisional classification of the *Graptolite-bearing portion* of the Skiddaw Slates:—

2. *d.* Milburn Beds = Uppermost Arenig or Lower Llandeilo.
   c. Ellergill Beds.
   b. *Tetragraptus* Beds { Upper, with *Didymograptus nanus.* / Lower
   a. *Dichograptus* Beds.
1. *Bryograptus* Beds = Tremadoc Slates.

An examination of sections drawn through the Skiddaw Slates, as, for instance, those constructed by the Officers of the Geological Survey, will show that these slates are greatly contorted. The contortion is often more violent than is represented on those sections. Study of natural sections of the Ellergill Beds, for example, shows that these deposits are constantly affected by overfolds having the middle limbs faulted out, and the same thing can be frequently detected in other parts of the series. The distribution of the fossils shows that little reliance can be placed on dips as an indication of the order of succession. For instance, the fossils obtained from the screes of Barf show that the *Bryograptus* Beds, the *Dichograptus* Beds, and the two divisions of the *Tetragraptus* Beds, must be developed *in situ* in that hill, or, in other words, that part of the Tremadoc and the greater portion of the Arenig Series is included in one or two hundred feet of rock. The same beds, with the exception of the *Bryograptus* Beds, are found on Outerside, where the beds are not on the same line of strike with those of Barf. Representatives of a considerable portion of the Arenig Series must also occur at Carlside Edge, and at several other localities. The thickness of the Ellergill Beds cannot be very great, and the probability is that the whole of the Graptolite-bearing portion of the Skiddaw Slates is not many hundreds of feet in thickness. Mr. Ward calculated the total thickness of the Skiddaw Slates at from 10,000 to 12,000 feet. This is probably an over-estimate, but the whole series must be far thicker than that portion containing Graptolites. Great masses of gritty rock occur which contain no Graptolites, and to the north of Skiddaw there is a considerable spread of red and green shales, which are very unlike the Graptolite-bearing Skiddaw Slates, but resemble beds referred to the Skiddaw Slates at Rake Beck, near Melmerby, in Teesdale, and at Ingleton. As these cannot be newer than the Graptolite Beds of the Skiddaw Slates, which pass up into the volcanic rocks of the Borrowdale group, they must be older. The Graptolitic Beds are, in fact, comparatively thin masses of deposit nipped in amongst older rocks in broken

synclinals. As to the age of the older rocks we have no evidence. They may be Cambrian, and some may be of even earlier date. The Skiddaw Slate period was certainly not one of continual deposition. Coarse detrital beds occur again and again. The Skiddaw Grit north of Skiddaw is often conglomeratic, and the included pebbles are of very varied type. Another conglomerate occurs on the old road from the Vale of St. John to Ulleswater, not far from Wolf Crag. It contains pebbles of slate in a greenish-grey argillaceous matrix. Many of these beds may prove fossiliferous, for they have been little searched, special attention having been hitherto paid to the Graptolitic rocks. I have obtained fragments of a large Trilobite from the banded black slates, associated with red and green slates, at the head of Hause Gill, north-east of Skiddaw. They may belong to an Arenig *Asaphus*, but may be older, and the locality deserves careful examination, for Trilobite fragments also occur in the green shales. Most of the Trilobites figured by Messrs. Goodchild and Postlethwaite[1] appear to be Arenig forms, but some may be older.

A few words may be said concerning Mr. Ward's divisions of the Skiddaw Slates. In his paper "On the Physical History of the English Lake District," he places the beds below the "Skiddaw Grit" in the Tremadoc Slates and Lingula Flags, those above that grit in the Arenig. The correlation of the very marked grit north of Skiddaw, with the much greater thickness of flaggy grits south of Skiddaw, the grits north-west of Bassenthwaite, and those near Buttermere is open to doubt. Furthermore, an examination of the map appended to his paper shows that, upon his interpretation, a great synclinal on the east side of the fault ranging down Derwentwater is brought against a great anticlinal to the west of that fault, a thing which certainly occurs in the district on a small scale, but which is difficult to imagine on so large a one. But the greatest objection to his proposed classification is furnished by the fossil evidence. According to his view, all the beds west of Derwentwater and Bassenthwaite, between the band of "Skiddaw Grit" north of Bassenthwaite and that north-east of Buttermere should be Tremadoc Slates or Lingula Flags; nevertheless, in this tract are situated Barf, Outerside, the Whinlatter Pass, Whiteside and other localities yielding abundance of Arenig fossils.

An examination of the Skiddaw Slate series shows that it is a group of deposits of great diversity of character, folded violently on a large and small scale; the uppermost beds, which are fossiliferous, represent part of the Tremadoc and the whole of the Arenig Series of North Wales. These beds are folded in boat-shaped synclines amongst what is probably a very much greater thickness of older rocks, the palæontology of which is practically unknown. It yet remains to discover the ages of these rocks, forming, perhaps, the greater bulk of the Skiddaw Slate formation, and this is a task which may well occupy the attention of local geologists for many years to come.

[1] Proc. Geol. Assoc. vol. ix No. 7.

(See *ante*, p. 125.

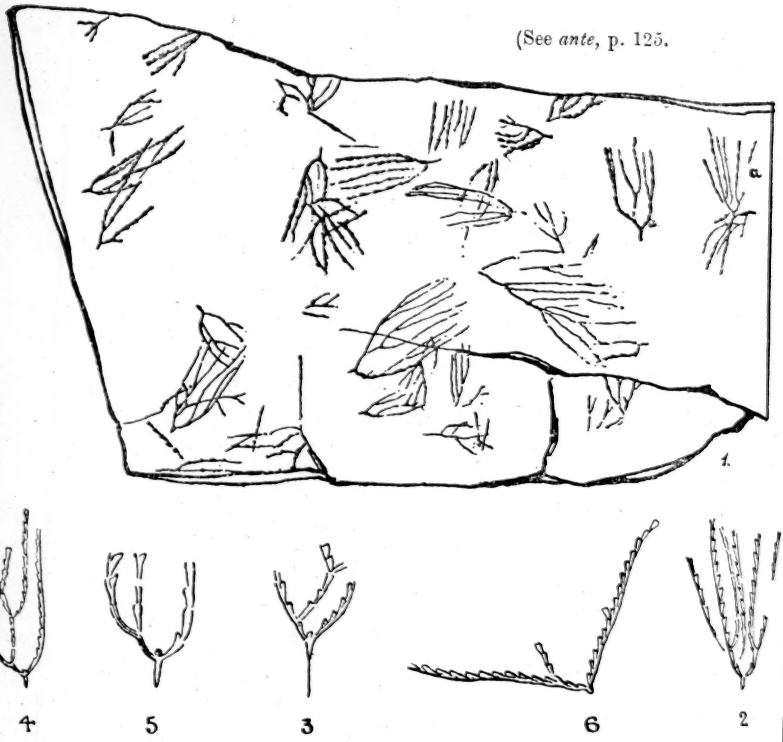


FIG. 1.—Slab with *Bryograptus ramosus*, Brög., nat. size, from Barf. Coll. J. Postlethwaite, F.G.S.

,, 2.—The Graptolite marked *a.* in fig. 1. × 2.

,, 3.—Proximal portion of *B. ramosus*. × 2. Barf. Coll. Miss Serjeant, Girton Coll.

,, 4.—*B. ramosus*. × 2. On same slab as Graptolite in last fig.

,, 5.—Proximal portion of Graptolite represented in fig. 4. × 4. Showing impression of virgula on left-hand primary stipe

,, 6.—*Bryograptus Callavei*, Lapw.? Barf. × 2. Coll. E. H. Tetley, Trin. Coll.

The specimens illustrated in figs. 3–6 are now in the Woodwardian Museum.

REVIEWS.

I.—THE CRINOIDEA OF GOTLAND. Part I. THE CRINOIDEA INADUNATA. With Ten Plates. By F. A. BATHER, M.A., F.G.S., Assistant in the British Museum (Nat. Hist.). Presented to the Royal Swedish Academy of Sciences, December 9, 1891. Kongl. Svenska Vetenskaps-Akademiens Handlingar. Bandet 25. No. 2. (Stockholm, 1893, 4to. pp. 200.)

OF the few places in the world from which fossil Crinoids can be obtained in anything like a fair state of preservation, showing stem, cup, and arms in their natural position, the Isle of

Gotland probably holds the first rank. The beautiful specimens procured during many years' close search in the well-known shales and limestones of that island have been for the most part carefully treasured in the Riks Museum at Stockholm, which thus becomes in a sense the Mecca of those who, like the author of this paper, devote themselves to the study of this group of fossils.

The Gotland Crinoids have, of course, frequently engaged the attention of the palæontologists of Sweden and of other countries as well. There is a reference to them in a mineralogical work by Bromell, recognizing their real nature, as early as 1739; and many papers by W. Hisinger, between the years 1799 and 1841, contain descriptions and figures of several species, of which the originals are still to be found in the Stockholm Museum. But the all-important work on these Crinoids is the "Iconographia Crinoideorum" of Professor N. P. Angelin, which was published posthumously under the auspices of the Royal Swedish Academy of Sciences in 1878. It is illustrated by 29 quarto plates, which Angelin left behind at his death, already lithographed, whilst the descriptive text in his own manuscript was edited for publication by his former colleague, Prof. S. Loven, who undertook the *Cystidea*, and by his successor, Prof. G. Lindström, who edited the main portion relating to the Crinoids proper. The comprehensive significance of Angelin's work may be understood from the fact that it contained descriptions and figures of 173 species of Crinoids, included in 42 genera, whereas, previous to its appearance, only 13 species, probably belonging to about 10 genera, were known from Gotland. In the interval since the publication of the "Iconographia" many important notices of the Gotland Crinoids have appeared at different times from such authorities as Von Zittel, Neumayr, Wachsmuth and Springer, P. H. Carpenter, F. A. Bather and others, but these appear to have been mainly founded on the published work of Angelin. A critical examination of this work and a comparison of its descriptions and figures with the original types in the light of the knowledge of the present day, was felt to be an absolute necessity to make it available for solving some of the crucial questions of Crinoidal structure and classification, more particularly in connection with British Silurian Crinoids; and this induced Mr. Bather to undertake a revision of the type-forms of Angelin and of such others as have been since discovered in Gotland. The authorities of the Riks Museum at Stockholm, amongst whom may be mentioned the well-known names of Professors S. Loven and G. Lindström, deserve the heartiest thanks of their fellow-workers in science for the facilities given to Mr. Bather to carry out his work, and a similar recognition will be awarded to the Royal Swedish Academy of Sciences for their truly liberal spirit in printing the results of the investigation in their Transactions and in the English language.

In this first section of the work the author treats only of such of the Gotland Crinoids as belong to the Order "Crinoidea Inadunata" of Wachsmuth and Springer. These are considered to be the

simplest forms of the group, and are characterized by having all the brachials free, and no interradial plates enter the dorsal cup unless in the posterior interradius. About 40 species of this group have been found in Gotland: 18 of these were described by Angelin, 6 by other authors, and 16 are quite new. They are included in 10 genera, only one of which, *Gothocrinus*, is new, and they belong to 7 families, all previously recognized. The following is the list:—

Family Pisocrinidæ. *Pisocrinus pilula*, de Kon., *P. ollula*, Ang., *P. pocillum*, Ang.
,, Heterocrinidæ. *Herpetocrinus Fletcheri*, Salter, *H. convolutus*, Hall, *H. Ammonis*, n. sp., *H. flabellicirrus*, n. sp.
,, Calceocrinidæ. *Calceocrinus gotlandicus*, Ang., *C.* cfr. *gotlandicus*, *C. pugil*, n. sp., *C. tucanus*, n. sp., *C. tenax*, n. sp., *C.* cfr. *tenax*, *C. nitidus*, n. sp., *C. interpres*, n. sp., *C. pinnulatus*, n. sp.
,, Dendrocrinidæ. *Homocrinus tenuis*, n. sp.
,, Euspirocrinidæ. *Euspirocrinus spiralis*, Ang.
,, Decadocrinidæ. *Gothocrinus gracilis*, n.g. et sp., *Botryocrinus ramosissimus*, Ang., *B. cucurbitaceus*, Ang., sp.
,, incert. *Streptocrinus crotalurus*, Ang., sp.
,, Cyathocrinidæ. *Cyathocrinus visbycensis*, n. sp., *C. acinotubus*, Ang., *C. striolatus*, Ang., *C. Dianæ*, n. sp., *C. glaber*, Ang., *C. muticus*, Ang., *C. distensus*, Ang., *C. longimanus*, Ang., *C. ramosus*, Ang., *Gissocrinus typus*, n. sp., *G. elegans*, Ang., *G. campanula*, n. sp., *G. umbilicatus*, Ang., *G. macrodactylus*, Ang., *G. goniodactylus*, Phill., sp. et var., *G. squamifer*, MS., *G. incurvatus*, Ang., sp., *G. verrucosus*, n. sp., *G.*, sp.

About 12 of these species occur in the Gotland beds "c" and "d," which are considered the equivalents of the Wenlock shale and Limestone in this country, whilst 32 species have been met with in the Crinoid and Coral conglomerate, bed "f", which is correlated with our Aymestry Limestone or Lower Ludlow. But two of the above species are fairly common both in Gotland and England, viz. *Pisocrinus pilula* and *Herpetocrinus Fletcheri*; the only other species occurring in the two regions are *Herpetocrinus Ammonis*, *Calceocrinus nitidus*, *Cyathocrinus acinotubus*, *Gissocrinus goniodactylus*, et var., and *G. squamifer*, so that, as the author remarks, the Crinoids afford but little assistance in correlating the strata in the two countries.

Although Mr. Bather adopts Wachsmuth and Springer's classification for the order Inadunata, he now substitutes, in place of their suborders, "Larviformia" and "Fistulata," the new divisions of the "Monocyclica" and "Dicyclica," the former possessing only one circlet of interradially situated basals, the latter having an additional circlet of infrabasals, radially situated between the basals and the stem. The Monocyclica will include all the genera placed in the Larviformia, with the possible exception of *Cupressocrinus* and the Gasterocomidæ, and the further additions of the Hybocrinidæ, Calceocrinidæ, Catillocrinidæ and perhaps *Belemnocrinus*. The Dicyclica, again, will comprise the three families of the Dendrocrinidæ, Decadocrinidæ and Cyathocrinidæ, and the provisional families Carabocrinidæ and Euspirocrinidæ. In this division there is a more regular pentamerous symmetry in the cup-plates than in the Monocyclica, and it is only in the right

posterior radial-plate that traces of bisection ever occur. This new arrangement is put forward tentatively, but the author claims that it is more philosophical than that for which it is substituted.

Among the many points of interest brought to light by Mr. Bather from the study of the Gotland Crinoids (and of those from the corresponding beds in this country) is the discovery of an anal plate in the dorsal cup of *Pisocrinus*, which thus determines the posterior interradius and proves the azygous plate to be a true radianal. This involves a complete change in the hitherto received orientation of the calyx plates in this genus, and brings it into harmony with the rest of the Monocyclica. The author proposes to add the genus *Calycanthocrinus* to the family Pisocrinidæ, as defined by von Zittel, and to remove from it *Catillocrinus*, Troost, on account of the absence of a radianal plate in this form.

In the family of the Heterocrinidæ are included the genera *Iocrinus*, Hall, *Heterocrinus*, Hall (*non* W. and S.), *Ectenocrinus*, S. A. Miller, *Ohiocrinus*, W. and S., *Anomalocrinus*, Meek and Worthen, and *Herpetocrinus*, Salter=*Myelodactylus*, Hall. This latter is the only genus represented in Gotland, and a nearly complete account of its morphology, mainly based on specimens of *H. Fletcheri*, Salter, from Dudley as well as from Sweden, is given. This genus is best known from the peculiar manner in which the stems with their two rows of cirri occur coiled up on the surface of the rock, giving a fanciful resemblance to a huge centipede; it is also further noticeable from the curious mistakes which have been made in the determination of fragmentary specimens referred to it. The forms first placed in the genus were some ossicles or joints of the stem, which Professor Jas. Hall mistook for portions of the arms and pinnules of the Crinoid, and described them as belonging to a distinct genus, which he named *Myelodactylus*. On this error Mr. Bather remarks, that "it should have been clear that the specimens, whatever they were, were not the brachials of a Crinoid; for the 'tentacles' were represented as two to each ossicle. *In no Crinoid is there more than one pinnule to a single brachial: such an occurrence is an evolutionary impossibility.*" (The italics are the writer's.) Prof. Hall's mistake was pointed out by J. W. Salter, who correctly described the stem and crown of the Crinoid, and, on the ground that the name proposed was based on false ideas, substituted for it the name *Herpetocrinus*. Strangely enough, in the present paper, Mr. Bather describes as the *stem* of a new species, *Herpetocrinus scolopendra*, an open helicoid coil with two short cirri to each ossicle; this *stem* is stated "to very closely resemble the arms of a Crinoid with cirri coming off as pinnules; with this important difference that each ossicle bears two cirri" —which is pronounced above to be an evolutionary impossibility. After this description was printed off, the clearing away of the matrix from the supposed stem and cirri revealed that these bodies were furnished with a ventral groove, and consequently that they were genuine arms, each brachial having a pair of pinnules in spite of the evolutionary impossibility of such a fact. The difficulty, how-

ever, is easily overcome by the author in pronouncing the pinnules to be "false," on the ground that though their structure is similar to that of true pinnules, yet they are articulated in the middle, instead of at the further end of the brachial!

In the family Calceocrinidæ are included the following genera: *Castocrinus*, Ringueberg, *Euchirocrinus*, M. and W., *Calceocrinus* (Hall), Ringueberg, and *Halysiocrinus* (Ulrich), Bather. These four genera are considered to represent an evolutionary series and not divergent branches, so that many forms of an intermediate nature might be expected to occur. A list of all the known species of these genera is given. *Calceocrinus* is the only genus of the series known in Gotland; one species had been described by Angelin, and to this six new ones are added by the author. One of the new forms, *C. pinnulatus*, differs from the type and all the other species in this genus in the possession of pinnules on the arms and in the plan of arm-branching.

Of the suborder Dicyclica, the first family treated is the Dendrocrinidæ, which is distinguished from the Decadocrinidæ by the continuous dichotomy instead of the single bifurcation of the arms, and from the Cyathocrinidæ by the constant occurrence of a plate in the anal area, the wide radial facet, and the more delicate tegmen. This family is divided into the Dendrocrinites and the Scaphiocrinites; in the former are included the genera *Merocrinus*, *Ottawacrinus*, *Dendrocrinus*, *Mastigocrinus*, *Homocrinus*, and *Parisocrinus*. Of these, only *Homocrinus*, Hall, is represented in Gotland by one species; the genus had only previously been known in America.

The family Euspirocrinidæ definitely includes only the genus *Euspirocrinus*, Ang., but two other genera, *Closterocrinus* and *Ampheristocrinus*, are associated with it provisionally. *Euspirocrinus* is described as possessing the dorsal cup of an advanced Dendrocrinite with the tegmen of a Cyathocrinite, whilst its arms might belong to either of these groups. The character of the tegmen of the calyx is well shown in an example of *E. spiralis*, figured by Angelin (Icon. pl. iv. figs. 7*d*. *e*), and reproduced on a larger scale by the author (p. 111, fig. 14). In this the food-grooves from the arms are continued along wide channels formed by the depressed edges of the large heart-shaped deltoidal plates, and these channels pass directly into the peristome, which is bounded on four sides by the deltoids and on the fifth by the madreporite plate. The channels are covered over by the ambulacral plates, which are fitted into small depressions in the deltoids.

The family Decadocrinidæ, previously proposed by Mr. Bather, may be divided into several series, but only one, Botryocrinites, is represented in the Gotland Silurian. This division includes the genera *Botryocrinus*, *Barycrinus*, *Vasocrinus*, *Atelestocrinus*, and a new genus, *Gothocrinus*, which is said to possess a *Dendrocrinus* cup with *Botryocrinus* arms. Under *Botryocrinus*, Ang., in addition to *B. ramosissimus*, Ang., the author also places *Sicyocrinus cucurbitaceus*, Ang., distinguished by its peculiarly curved ventral sac,

which is built up of a median dorsal row of plain hexagonal plates lying between similar rows of plates folded on their outer sides, and thus it differs hardly at all from the ventral sac of *B. ramosissimus*. The author failed to find any pores or slits in the ventral sac, but there appears to be an anal opening bordered by small plates nearly at the base on the posterior side of the sac (pl. vi. fig. 183).

The genus *Streptocrinus*, W. and S. (= *Ophiocrinus*, Ang., not Salter,), cannot at present be placed in any recognized family. The only known species, *S. crotalurus*, Ang., sp., is solely represented by mere fragments, amongst which are the curled-up pinnulated arms, supposed at first to be the stems with cirri of a species of *Herpetocrinus*. The paired pinnules possess a broad V-shaped ventral groove, covered by quadrangular plates similar to those of the brachials. The author considers that they have arisen as merely processes of the brachials, and they are termed, as already mentioned, "false" pinnules.

The important family of the Cyathocrinidæ is defined as Inadunata, Fistulata, Dicyclica, with no radianal or tube-plate in the anal area of the dorsal cup; with the anal x-plate either present in the cup or raised above it; with five arms, simple and dichotomous, and with a rather solid tegmen. To *Cyathocrinus* itself 14 species from Gotland were referred by Angelin, but some of these turn out to be synonyms, and others were not well founded, so that now only 9 species remain, and two of these are new forms. In *C. acinotubus*, Ang., and in some other species of this genus as well, the author describes and figures some very interesting structural features in the ventral covering-plates of the arm ossicles, which exhibit a very elaborate arrangement of their articulating surfaces. Each covering-plate appears, from the exterior, to be divided by a suture, and on the interior there is a small round ossicle. The edges of the ventral groove are also marked off into concave subcrescentic facets for the articulation of the covering-plates, and each facet has a median notch. The proximal articulating portion of the covering-plates is similarly marked off. These structures are well shown on pl. vii. figs. 208–213, 243–247, and pl. viii. figs. 249–250, 254–256.

The genus *Gissocrinus*, Ang., is numerously represented in Gotland, and 10 species are described. This genus has generally been considered as differing from *Cyathocrinus* only in having three instead of five infrabasals, but the author points out that it is further characterized by the very distinct axial ridging of the cup-plates, the lateral compression of the distal portions of the arms, the elevated or cornice-like rim at the distal ends of the brachials, the strong transverse folding of the plates of the ventral sac, and its length and lateral compression. The covering-plates of the brachials in some species are even more complicated than in *Cyathocrinus*. In some instances, as in *G. typus* for example (pl. viii. figs. 273–275), they form such a close-fitting series that it is difficult to see how the food-grooves can have communicated with the exterior, unless it were at the distal ends of the arms.

The above desultory notes on the contents of this Part (I.) will,

perhaps, enable even those not specially acquainted with fossil Crinoids to understand, to some extent, the importance of Mr. Bather's work in relation to these organisms. The minutely detailed descriptions which he has given of the structural characters of the different species, and the abundant and faithful illustrations, render the particular features on which their classification depends easy of recognition, and thus will amply compensate for the brief diagnosis and the artistically (but too frequently erroneously) restored figures in Angelin's great work, which have not seldom proved confusing to the more critical students of the present day. We very cordially congratulate the author on the amount and excellence of the work performed during the "vacations" of two years, and the Swedish Academy on their success in getting their almost unrivalled collection of Crinoids made available for the service of science a second time. We cannot, however, conclude this notice without expressing a feeling of regret that the grand collection of British Silurian and Carboniferous Crinoids in our own Natural History Museum should up to the present remain practically undescribed and unknown to the scientific world. Mr. Bather has, indeed, commenced to describe them in some papers which have appeared at intervals since 1890 in the Annals and Mag. Nat. Hist., but, when we compare the humble scale of these with the elaborate Part I. now before us, the contrast is so striking that we are tempted to enquire why there should not be prepared a "non-vacation" work on the fossil Crinoids in the British Museum, on the same pattern as that which our author has so well carried out for the Swedish Academy by way of a holiday exercise? The writer of the review on Angelin's Iconographia, which appeared in this MAGAZINE in 1878, commented on the neglect in the treatment of these organisms in our country, but scarcely anything has been done in the interval to remedy it. It is high time that the reproach should be removed, and it is to be hoped that before long our home Crinoids will be as adequately treated as those of Gotland.

G. J. H.

II.—UEBER EIGENTHÜMLICHE OBSIDIAN-BOMBEN AUS AUSTRALIEN. Von HERRN ALFRED W. STELZNER in Freiberg i. S. Zeitschr. d. Deutschen geolog. Gesellschaft, Jahrg. 1893, pp. 299—319, pl. vi.

ON SOME PECULIAR OBSIDIAN-BOMBS FROM AUSTRALIA.

THE bombs described by Dr. Stelzner in this paper were found on the surface of the ground at Kangaroo Island, S.W. of Adelaide; in the region of Macdonnel Range in Central Australia; and in the great Victoria desert between the Everard Range and the Fraser Range. Similar bombs are also reported to occur in other parts of Australia, more particularly in the North and West; and Charles Darwin, in the "Volcanic Rocks of the Island of Ascension," describes and figures a fragment of a similar bomb found on the sandy plains between the Darling and the Murray.

In none of the areas in which these bombs occur is there any indication of either active or extinct volcanoes, and the question of their distribution is a problem which the author does not attempt to solve.

The specimens all consist of a black compact and homogeneous glass, with a very few small and isolated gas inclusions, but no crystals of any kind. The specific gravity varies between 2·41 and 2·52. There is no doubt that the bombs are really of Obsidian, and that they are volcanic in origin. One specimen is polyhedral in form, others are rounded or ellipsoidal, with the peculiarity that they appear as if built up of two distinct halves, one somewhat flattened and larger, the other more convex and smaller. In two instances the form is that of a button-shaped mushroom; as if the smaller of two rounded thick-walled shells had been pressed into the concavity of the larger. One specimen is a hollow sphere, which may have been simply a large bubble enclosed by glassy walls. In this hollow bomb and in the mushroom-like forms there are on the larger and flatter hemisphere, and on this only, from four to six ring-like elevations parallel with the equatorial margin, as well as fine straight or wavy lines, having a meridional direction; and further, this flatter half has a distinctly varnished appearance in contrast with a dull aspect on the other more convex half of the bomb.

The peculiar form of these bombs, and the pittings and other markings on their surfaces, are attributed to the resistance which they encounter in their flight through the atmosphere, and their individual differences probably depend on the greater or lesser plasticity of the lava when the explosion takes place, and the varying rapidity of the projectile and the consequent varying force of the resistance of the atmosphere. The bombs examined range from 15 mm. to 55 mm. in their greatest diameter.

III.—1. Presidential Address: The Cretaceous System in Canada. By J. F. Whiteaves. (Transactions of the Royal Society of Canada, Section IV. 1893, pp. 3–19.)

2. Note on the Recent Discovery of Large Unio-like Shells in the Coal-measures at the South Joggins, Nova Scotia. By J. F. Whiteaves. (Transactions of the Royal Society of Canada, Section IV. 1893, pp. 21–24.)

1. THE first of these papers contains an interesting summary of the Cretaceous system of Canada from the palæontologist's standpoint, and as it proceeds from the pen of one of the best authorities on the American Mesozoics the views put forth in it carry weight.

The literature of the subject dates from the year 1857, at which time F. B. Meek, that most accomplished of American palæontologists, described some fossils from the Cretaceous rocks of Vancouver Island (Trans. Albany Institute), and in the same year Dr. J. S. Newberry discussed the age of the rocks associated

with the Coal on Vancouver Island, and concluded upon palæontological evidence that they were Cretaceous. In the following year, Dr. B. F. Shumard (Trans. St. Louis Academy of Sciences) described some fossils from the Cretaceous rocks of the Nanaimo River. He was followed, in 1859, by Prof. Leo Lesquereux, who, in the 27th volume of the American Journal of Science and Art, described some fossil plants from the same rocks belonging to the genera *Populus*, *Quercus*, and *Cinnamomum*, which, however, he regarded as of Miocene age. Captain Palliser's explorations in British North America were fruitful in palæontological results, worked out by Dr. (now Sir James) Hector. In the same year (1859) fossils collected in the country between Lake Superior and the Red River Settlement, and between the latter and the Assiniboine and Saskatchewan rivers, were sent to Mr. E. Billings, then palæontologist to the Geological Survey of Canada, who found that the specimens supplied "almost indisputable evidence that a considerable part of the territory belongs to the Cretaceous period, or the great Chalk formation so largely developed in the Old World." In 1861 Dr. Hector, in a paper on the geology of the country between Lake Superior and the Pacific Ocean (Palliser's Expedition, 1857–60), compared the Cretaceous rocks east of the Rocky Mountains with those of Vancouver Island, and published an ideal vertical section of the Cretaceous system in British North America, which agrees in part with Meek and Hayden's Upper Missouri section. Lists of the Cretaceous fossils were contributed by Mr. Etheridge; but most of the fossils were only determined generically. Nineteen species were recorded, all marine mollusca. Eleven of these were from various localities now called Manitoba and the districts of Assiniboia, Saskatchewan and Alberta, and eight from Nanaimo, Comox or Valdez Inlet. No less than thirteen of the species are identified with Texan or Mexican species. Again, in 1861, Meek described the following Cretaceous fossils from Vancouver and Sucia Islands, viz.: *Dosinia tenuis*, from Nanaimo; *Inoceramus subundatus*, *Baculites occidentalis*, *Ammonites Vancouverensis* and *Nautilus Campbelli*, from Comox; *Ammonites complexus*, var. *Suciensis*, from Comox and the Sucia Islands; and *Baculites inornatus* from the Sucia Islands. A few plants were described in 1863 by Dr. Newberry (Boston Journ. Nat. Hist. vol. vii.), viz. *Aspidium Kennerlyi* and *Taxodium cuneatum*, from Nanaimo; also *Populus rhomboidea* of Lesquereux and a *Sabal*, afterwards described by Sir J. W. Dawson under the name of *Sabal imperialis* (Trans. Royal Soc. Canada, sec. 1). The first volume of the Palæontology of California (1864) contains descriptions, by W. M. Gabb, of two new species from Nanaimo, viz. *Hamites Vancouverensis* and *Pecten Traskii*. Since the confederation of the provinces of Canada in 1867, much work has been done upon the Cretaceous rocks of Manitoba and the North-West Territories and in the Rocky Mountains and British Columbia by Sir J. W. Dawson, Doctors Selwyn, G. M. Dawson, R. Bell, and J. W. Spencer, and by Messrs. J. Richardson, R. G. McConnell, and J. B. Tyrrell. In summarizing

the results of the work of these geologists Mr. Whiteaves follows the Cretaceous rocks in a direction from east to west geographically, and in a descending order geologically, thus: (1) Manitoba and the North-West Provinces; (2) the Rocky Mountain region; (3) British Columbia, inclusive of the islands off the Pacific Coast; (4) the Yukon district.

In Canada, as in the United States, it is found convenient to adopt a single division of the Cretaceous system and to draw the line between the Upper or Later and the Lower or Earlier North American Cretaceous, as nearly as possible at the base of the Dakota Group, or of that of its local representative.

Manitoba and the North-West Territories.—In these regions all the Cretaceous rocks, as yet examined, appear to be referable to the Upper or Later North American Cretaceous, as defined above. "It is still doubtful," observes Mr. Whiteaves, "whether the Laramie formation of Canada should be regarded as forming the summit of the Cretaceous or the base of the Tertiary system, though, at present, the consensus of opinion among geologists would seem to favour the former view. In mapping the northern part of the district of Alberta, Mr. Tyrrell found that the Laramie there is divided into two series, and has expressed the opinion that its upper portion, which he proposes to call the Pascapoo series, is of Eocene age, and that its lower portion, which he calls the Edmonton series, and which is equivalent to Dr. Dawson's 'St. Mary River series,' of Southern Alberta, is Cretaceous. This division is based mainly upon palæontological evidence, and more especially upon the circumstance that the Edmonton series is now known to contain numerous remains of Dinosaurs (*Lælaps*, etc.), and that it is the highest horizon in Canada at which Dinosaurs are known to occur." The divisions adopted for the rocks of Manitoba and the North-West Territories are: (1) The Laramie, in whole or in part; (2) The Pierre-Fox Hills or Montana formation; (3) The Belly River series; (4) The Niobrara-Benton, or Colorado formation; (5) The Dakota. It was found that in this region it was no longer practicable to separate the Fox Hills group from the Fort Pierre group, nor the Niobrara from the Benton.

The Rocky Mountain Region (inclusive of the Foot Hills).—In this region the Cretaceous rocks occupy the bases of narrow troughs in the Palæozoic rocks. The fossils consist of the remains of plants or of marine invertebrata. By means of the plants Sir J. W. Dawson recognized three horizons in this region, viz. (1) The Mill Creek series; (2) The Intermediate series; (3) The Kootanie series. The following estuarine or purely marine divisions of the distorted Cretaceous rocks of this region have been recognized: (1) The Laramie; (2) The Pierre-Fox Hills, or Montana formation; (3) The Niobrara-Benton, or Colorado formation; (4) The Devil's Lake Deposit.

British Columbia and the Islands off the Pacific Coast.—The Cretaceous rocks of this region are taken in the following order: (1) The Nanaimo group of Vancouver and the adjacent islands; (2) The

Queen Charlotte Island series; (3) The Cretaceous at other localities in the province. It is judged from palæontological evidence that the lower and middle, or most fossiliferous, subdivisions of the Nanaimo group are referable to the Upper or Later rather than to the Lower or Earlier North American Cretaceous. The Queen Charlotte Island Cretaceous has been thoroughly investigated, first by Mr. James Richardson, and later by Dr. G. M. Dawson. Numerous fossils have been collected by both these explorers, and they have been described by Mr. Whiteaves in his "Mesozoic Fossils," published by the Geological Survey of Canada. Cretaceous rocks occur also at Tatlayoco Lake, Jackass Mountain, Sigutlat Lake, and the Iltasyouco River, all on the mainland.

The Yukon District.—This district, though included in the North-West Territories, is geologically more nearly related to British Columbia, and it is therefore considered here. Fossil plant remains (reported upon by Sir William Dawson) were found by the members of Dr. G. M. Dawson's exploring expedition of 1887–1888 (Geol. Surv. Canada, 1889). Some new species of marine invertebrates were also obtained by Dr. Dawson at Rink Rapids, viz. *Discina pileolus* (afterwards changed to *D. Dawsoni*), *Cyprina Yukonensis*, *Schlœnbachia borealis*, and *Estheria bellula* (Contributions to Canadian Palæontology). Finally, in 1888, Mr. R. G. McConnell discovered rocks holding *Scaphites*, resembling one of the Benton species, on the Porcupine River, fourteen miles below the mouth of the Bell River, and further down the Porcupine he found sandstones full of one of the varieties of *Aucella Mosquensis*.

No less than 108 species of fossil plants have been recorded or described, up to the present time, from the Canadian Cretaceous, exclusive of the Laramie, or 179 species including the Laramie; and 358 species of animal remains from the undoubted Cretaceous rocks of the Dominion are now known, or 394 if the Laramie be included. Mr. Whiteaves concludes his Address by saying that "a comparatively small portion of the Cretaceous rocks of Canada has been examined in any detail, and more or less isolated areas of these rocks are known to exist in parts of the Canadian North-West, about which scarcely any other information has been obtained. Still, the facts, as summarized in this Address, are sufficient to show that substantial additions to our knowledge of the geographical distribution, of the economic products, and of the fossil flora and fauna of the Cretaceous rocks of Canada, have been made within the quarter of a century that has elapsed since the confederation of the Provinces."

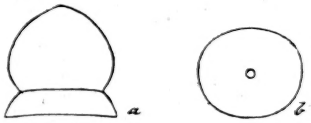
2. In the second paper before us an account is given of the discovery of two very large Unio-like shells, for which the author proposes the new generic name *Asthenodonta* (ἀσθενης, weak, in the sense of feebly developed; and οδους, a tooth). In passing in review the literature of the subject of the ancient representatives of *Unio*, *Margaritana* and *Anodonta*, it is remarked that fresh-water shells belonging to these genera have not yet been satisfactorily recognized in rocks older than the Trias. In justification of the rejection of

these names for fossil genera, Mr. Whiteaves quotes the late Dr. S. P. Woodward (Manual of the Mollusca, p. 414) that the molluscan genera of the older rocks "are believed to be nearly all extinct, for although the names of many recent forms appear in the catalogues of Palæozoic fossils, it must be understood that they are only employed in default of more exact information." Thus the *Anodonta Jukesii* of Forbes, from the Upper Old Red Sandstone of Ireland, is the type of the recently proposed genus *Archanodonta*; and, similarly, the species described as *Unio* by Sowerby, Phillips and others, from the Coal-measures of Great Britain, are now referred to *Anthracosia* or *Anthracomya*. "But although there is at present no satisfactory evidence of the existence of any of the recent genera of Unionidæ in rocks of Palæozoic age, the family seems to have been then represented by extinct genera, such as *Amnigenia* (and possibly *Archanodonta* in the Devonian), by *Naiadites* or *Anthracomya* in the Carboniferous, and by *Palæomutela* and *Palæopleidon* in the Permian." The specimens of *Asthenodonta Westoni* (the subject of the paper) were found associated with large fragments of *Sigillaria* and *Lepidodendron*, leaves of *Cordaites*, and a piece of the lower jaw of a reptile. The stratigraphical position of the sandstones in which the remains occurred is believed to be between Coal Groups 31 and 32 of Sir J. W. Dawson's South Joggins section, as described in the Accadian Geology. The external contour of *Asthenodonta Westoni* is not unlike that of large specimens of the freshwater pearl mussel (*Margaritana margaritifera*, Linn.), but the beaks are more nearly terminal and the posterior termination of the valves more pointed below. The test is very thick, and shows nacreous structure under the microscope. There are no traces of lateral teeth in either valve, and the hinge dentition as a whole, so far as it can be ascertained, is in some respects comparable with that of *Anthracosia*. Until, however, the hinge dentition of both of its valves is more perfectly known, the exact systematic position of *Asthenodonta* will be uncertain; but it is considered by its describer to represent an aberrant and extinct type of Unionidæ. The length of the most perfect specimen collected was 200 mm.; height in the centre 90 mm.; maximum breadth or thickness of the two closed valves, about 42 mm.; thickness of the anterior end of the test of one valve, 9 mm. ARTHUR H. FOORD.

IV.—THE PROTOCONCH OF *ORTHOCERAS*. By J. M. CLARKE. (The American Geologist, Vol. XII. August, 1893, pp. 112–115.)

THE fortunate discovery of a perfect specimen of the extreme apex of an *Orthoceras* has enabled Mr. J. M. Clarke to supply information, hitherto wanting, as to the nature of the protoconch or initial chamber of that genus. Specimens showing the penultimate chamber, with external cicatrix, have long been known, both from the Carboniferous limestone of Belgium and from the Triassic beds of St. Cassian. De Koninck has figured the Belgian examples (Ann. Mus. Roy. d'Hist. Nat. Belg.), Hyatt those of St. Cassian

("Genesis of the Arietidæ"). Branco regarded the cicatrix-bearing conical end of the shell in *Orthoceras* as the embryonal shell or protoconch ("Anfangskammer"), but Hyatt, observing a wrinkled, wart-like lump at the apex of the St. Cassian specimens, came to the conclusion that this was the true protoconch, and assumed from its shrunken condition that it was originally composed of conchiolin and hence easily destructible. The specimen (see Figure) which is the subject of Mr. Clarke's very interesting communication was found in the Styliola limestone of the Genesee shales, on Canandaigua Lake, New York State, in an association of species which represents the earliest appearance in North America of the [Upper Devonian] fauna of *Goniatites* (*Gephyroceras*) *intumescens*, Beyrich. The specimen "consists of the first or apical chamber of the shell, to which the protoconch is attached. The upper end of the specimen shows the first septum . . . . to be circular and with a central sipho. The lateral walls of the first chamber taper rapidly to the plane of conjunction with the protoconch, and its depth is about one-half that of the latter. The protoconch itself is semi-ovoid in shape, and



a. Outline of the first chamber of an *Orthoceras* with protoconch attached; *b*, base of the first chamber (*a*) showing siphuncle. Greatly enlarged.

when compared with those of *Orthoceras* previously described or figured [in the shrunken condition] is of very large size. It shows no indication of shrinking or other irregularity and its distal extremity is perfectly smooth. The length of the entire specimen is ·85 mm.; that of the protoconch, ·60 mm.; and the diameter of the first septum, 1 mm." Mr. Clarke observes in the concluding part of his paper that "it is probable that this protoconch has been derived from a shell so young that atrophy and wrinkling have not manifested themselves, as they may have done with the more mature development of the shell. This, I believe, is the only recorded observation of the protoconch in Palæozoic forms of *Orthoceras*, and its shrunken condition in the post-Palæozoic forms may have a phyletic significance." — Arthur H. Foord.

REPORTS AND PROCEEDINGS.

Geological Society of London.

I.—January 24th, 1894.—W. H. Hudleston, Esq., M.A., F.R.S., President, in the Chair. The following communications were read:

1. "The Ossiferous Fissures in the Valley of the Shode, near Ightham, Kent." By W. J. Lewis Abbott, Esq., F.G.S.

The fissures occur in a promontory of Kentish Rag between two tributaries of the Shode. There are four fissures in this promontory, striking at right angles to the valley. Details of the physiography

of the area in which the fissures occur are given in the paper. Three of the fissures have obviously been in contact with the surface, and from these the bones appear to have been dissolved out. The fourth does not reach the top of the Rag, and, further, is sealed by an aragonite-lined chamber with stalactitic floor and ceiling. This fissure is from 2 to 6 feet wide and about 80 feet deep, and is filled with a heterogeneous collection such as constitutes the flotsam and jetsam of streams, along with materials derived from the rock in which the fissures occur. Several thousand bones were found, also twelve species of aquatic and land shells, an entomostracan, *Chara* and other vegetable remains have been procured.

The author gives reasons for concluding that the fissures have never been re-opened since they were first closed by the materials introduced into them by the river, and that all the contained fossils belong to one and the same geological period. He points to the discovery of species not before found in Pleistocene beds as only a repetition of what has occurred in other sections he has worked, and remarks also that the increase of species is corroborative of a suggestion of Mr. C. Reid that the more we discover of the smaller creatures of this and the preceding age, the more they approximate to those of our own times. Even if we were to exclude from the lists all the species not previously found fossil elsewhere, we still have an extensive assemblage of the older Pleistocene forms, which must have lived during the filling of the fissures, and this, therefore, fixes the filling operation as having occurred in Pleistocene times.

2. "The Vertebrate Fauna collected by Mr. Lewis Abbott from the Fissure near Ightham, Kent." By E. T. Newton, Esq., F.R.S., F.G.S.

The vertebrate remains collected by Mr. Lewis Abbott are passed in review, and, as far as possible, specifically identified: they represent mammals, birds, reptiles, and amphibians; but no fishes have been found. In all, forty-eight different forms have been recognized; three, or perhaps four, are extinct; eleven are extinct in Britain, but are still living elsewhere; twenty-one are living in Britain, but are known to be Pleistocene or Forest-bed forms; and twelve are species now living in Britain which have not hitherto been recognized in Pleistocene or older deposits.

Among the more important species found in this fissure, but extinct in Britain, may be noticed, besides *Elephas primigenius*, *Rhinoceros antiquitatis*, and *Hyæna*, the *Ursus arctos*, *Canis lagopus*, *Myodes torquatus*, *Myodes lemmus*, *Microtus gregalis*, *M. ratticeps*, *Lagomys pusillus*, *Spermophilus*, and *Cervus tarandus*. The name of *Mustela robusta* is proposed for some limb-bones intermediate between the Polecat and Marten, and the remains of an extremely small Weasel are noticed as a variety of *Mustela vulgaris*. Although the large number of living species gives a recent aspect to this series of remains, the evidence, it is believed, points rather to their being all of Pleistocene age, and most nearly allied to the fauna of British caves.

RAPID ELEVATIONS: A SELF-CRITICISM.

SIR,—In the GEOL. MAG. for 1892 (p. 405), I published a note on the possible effects from Rapid Elevation of submerged lands, in reference to Prof. Prestwich's paper on the Rubble Drift of southern England. In it I said: "Most violent Japanese earthquakes exhaust their potency in vibrations measured by inches or less." I am not aware that any measurement of vibrations have, even now, given any larger values. But after reading a paper by Prof. Koto on the great Japanese earthquake of October, 1891, it does not seem correct to say that their potency is exhausted in small vibrations. Prof. Koto gives both descriptions and photographs of effects from this prodigious convulsion, and these include the formation of a visible fault-line more than 70 miles long, with a relative horizontal displacement of its two sides along its direction, of from 3 to 6 or even as much as 12 feet in length, and with a relative vertical displacement producing a step along the fault, whose height sometimes reached 20 feet.

Prof. Koto gave attention to the question whether this step was due to a rise of the region on one side, or a fall of that on the other. We might expect that the effects on watercourses would have afforded a criterion; however, he judges that the evidence is insufficient for a decision. He regards fall as more probable, but mentions that, while in general the western side of the fault is lower, along one portion it is higher, and concludes that here at any rate must be an uplift, for which accordingly he conjectures an explanation. His conclusion is natural and probable. Still it is not quite impossible that the cause of the dislocation may here have changed sides of the fault. If water be drawn off from a frozen canal, the sinking ice breaks with a longitudinal crack; but we should not be surprised to find the two sides of the crack irregular in their relative levels. Prof. Prestwich's theory assumes rapid elevations. The throw of this fault is thus not proved to be an elevation. Also how rapid was it? This most interesting question does not seem to have occurred to the investigator. He describes a great shock, followed by less intense repetitions so numerous that 100 were counted during the remainder of the day, and 300 in the day following. Their frequency diminished, yet so gradually that after the lapse of a fortnight they still averaged more than one per hour. Surely these numerous disturbances had a share in the visible effect. What part was produced by them, what part by the great convulsion? How nearly was the change "instantaneous?" The slope of the fault-step is described as being the angle of repose of the material; but this would be the natural result of frequent shocks, and affords no argument as to the change being a single effect. Any evidence on this subject would be most interesting and valuable.

It appears, then, that this Japanese Earthquake does not afford an undoubted instance of such a Rapid Elevation as Prof. Prestwich's theory assumes. Nevertheless the argument in my note against the credibility of the theory is weakened, for one of my main data is now not unquestionable.

E. HILL.

THE RECTORY: COCKFIELD, R.S.O. SUFFOLK.